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THE
ANALYSIS AND SOFTENING
OF
BOILER FEED-WATER

BY

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PREFACE TO THE SECOND EDITION.

THIS work undertaken with the collaboration of a chemist is made necessary in consequence of numerous subsequent inquiries regarding the essay appearing in the Journal for the Advancement of Railway Interests (Organ für die Fortschritte des Eisenbahnwesens) of the year 1893 On the Examination and Softening of Boiler Feed-water (Ueber die Untersuchung und das Weichmachen des Kesselspeisewassers).

In the above new work it was sought to show the chemical procedure on which water purification is based, and exhibit a short and simple water analysis, and method of calculating the quantities of reagents required for water softening to be used in practice. In it the information most vitally needed for practical water analysis and purification is reiterated and the other results of my previous essay are presented for use. Besides this, the report on feed-water was written opportunely by the author for the commission of Austrian Railway Managers at the Railway Exposition (Paris, 1900), and as a result it was followed by the Report of the Technical Committee of the Society of German Railway Managers which was drawn up in the year 1902

The new treatises taken into consideration are: Critical Studies on Analysis and Purification of Boiler Feed-water (Kritische Studien über Untersuchung und Reinigung des Kesselspeisewassers), by private lecturer J. Pfeifer of Budapest (Zeitschrift für angewandte Chemie, 1902, Heft 9) and Prof. Blacher's treatise: On the Analysis of Feed-water and the

Control of Water Purification (Ueber die Untersuchung des Kesselspeisewassers und die Kontrolle der Wasser-Reinigung, Riga, Verlag von N. Kymmel, 1903). From the first is taken the excellent method of Pfeifer for the determination of magnesia, and from the latter is taken the hint on the necessity of warming the sample of water for the determination of the hardness by means of soap solution, as well as the importance of the removal of the free carbonic acid by means of a blowing in of air.

Regarding the work of Prof. Blacher, the priority of the method of reducing the several materials to calcium, for the first time generally applied by the author and offering so many advantages to the operator, must in truth be ascribed to a letter of Prof. Kalmann in Bielitz of July 29, 1892, to the author, in which he says:

"In reference to your method of calculating everything to degrees of hardness, I am in complete accord with it and I see therein a very beneficial simplification of the calculations for the non-chemist, to whom the reduction of one compound into the equivalent quantity in another appears very difficult."

In Blacher's article the method of easily controlling the purified water is developed in a very instructive way; still the author cannot explain intelligently the control by means of the number of drops; on the contrary an inaccuracy will surely occur by and by, as the drops do not always have the same size. The result will be much more certain and clear if the analysis is conducted according to the author's procedure, in which 56 c.c. of the liquid to be analyzed is measured out and this titrated with 2/10 normal HCl from a burette graduated in 1/10 c.c. Each 1/10 c.c. of acid used will then correspond to a degree.

That the author has still held to Knofler's way of determining the magnesia instead of Pfeifer's method, after the appearance of the latter's method of magnesia determination, is explained by the fact that he has obtained sufficiently satisfactory results by Knofler's method. The person interested in the magnesia determination must always take care, whether he uses caustic soda in an alcoholic solution according to Knofler or lime-water according to Pfeifer, that both liquids are analyzed for their strength in caustic soda or lime before using them.

As to the use of a mixture of methyl orange and phenolphthalein as an indicator, a serious objection cannot be made against the exclusive use of these indicators, because it gives a simple rapid technical water analysis whose accuracy is not carried out to milligrams.*

This being granted, it is now permissible to indicate the special purpose of this treatise, which consists in giving to the user of a water-purifying plant a guide to the operation, and to be of assistance in the installation of such machines.

It sometimes happens in spite of the most complete chemical analysis (to which will be added usually instructions for purification of the water) that the purification when carried on for a time will not accomplish uniformly satisfactory results, because the person entrusted with the water purification lacks the knowledge of the leading conditions on which good results depend.

This knowledge was until now possessed only by the chemist or by the expert engineer of the contractors who installed the water-purifying apparatus. Usually these fixed once for all, at the time of installation of the apparatus, the distribution of the reagents to the raw water and therefore could not foresee the changes naturally taking place later in the raw water, as well as the necessary changes in the character of the reagents. The result of this was often, therefore, that water-purifying plants, which worked well in the first place, later would not answer the requirements, and the user of the boiler often deplored the great outlay he had made. If now the condition occurs that the water after the chemical purification wastes away the pipes, the rivets of the fire-box, the adjoining iron parts, or, when possessing certain characteristics, attacks the copper parts, then the purchasers often show the greatest embarrassment; indeed it sometimes happens, in spite of the resistance of the boiler-scale, that the safety of the plant and that of the boilers themselves is affected by the weakening of the plates or their means of fastening, in consequence of corrosive action of feed-water changed by purification or by the unhindered entrance of the same after the removal of the scale-forming matter.

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* Water containing ammonia, for which methyl orange fails as an indicator, will hardly ever be used for boiler feed-water. They are dangerous to the boiler, as they usually contain nitric and nitrous acid. The refusal of methyl orange to answer with such waters is therefore a sure indication that such waters should not be used.

But these bitter experiences would have been spared the user of the boilers if he had personally obtained a true conception of the character of his raw water, of its eventual changes (in the raw condition and in the boiler), and of its influence on the boiler materials before the installation of the purifying-plant; and if he had constantly investigated for himself the strength of his reagents, the strength of the reagent liquids created from the above, and the uniformity of the pure water during the operation of the plant, and had made himself certain by frequent personal examination that no neglect occurred in the attendance of his purifying-plant.

But usually the services of a chemist are not available for the boiler-user, and as he is dependent solely on himself and his organization, the necessary standards are not adhered to.

It is therefore indispensable that he must be familiar with the characteristics of his water in all the forms in which it is used (raw, reagent, or pure water), just as he is familiar with the properties of the coal and other materials which he uses or manufactures.

It must be possible and of importance to him to acquire the knowledge demanded by the character of his water.

He should be in position to use up his existing plant, in order to know how eventually to install a cheap and good water-purifying plant himself with the help of existing reservoirs or tanks.

Finally he should be in position, if he must install a new continuously operating water-purifying device, to judge if the arrangement under consideration suits his conditions and if the often excessive price is proportioned to the achieved softness of the water, and the freedom of the apparatus from constant attendance, etc., are founded on facts. He will also recognize whether it is not more advantageous to obtain it in some other way—whether to obtain at greater cost—a good feed-water, either by bringing it in or by deep borings.

Fortunately the acquirement of this knowledge is possible by one's own efforts even to a person who is not a chemist; and it is the mission of this treatise to give to those interested in boilers the necessary insight to the inner processes by which water purification prevents scale formation and the maintenance of the conditions required to accomplish the same.

The acquirement of the knowledge regarding water analysis and softening according to the following treatise is not difficult, as the real analysis of raw water, the calculation of the necessary additions for the purification of boiler feed-water and the softening itself requires but very little chemical study and requires only very simple exercise, reading and calculation.

Also the use of the following methods has the advantage that the analysis of the water, and the calculation of the amounts of reagents which must be added to the same, may be finished in an hour, and that the preparation of the reagents and the treatment of a test sample can be completed in from three to six hours, while the result of the softening itself can be proved correct in several minutes.

For this we use:

1. The Knofler system for determination of the carbonic acid, the magnesia, the total lime, and finally the sulphuric acid (Liebig's Annalen der Chemie 1885, Band 229).
2. The Pfeifer system for the determination of the magnesia (Zeitschrift für angewandte Chemie 1902, Heft 9).

3. The Kalmann formulas (Mitteilungen des technologischen Gewerbemuseums in Wien, IV. Jahrgang 1890).

The analysis of the water is made by means of a travelling-case designed by the author and weighing 8 kg, in which all the apparatus and chemicals necessary for the analysis of the water are contained. It is obtainable from Rohrbeck's Nachfolger, Wien, I, Karntnerstrasse.

With reference to the necessary measures for water softening itself, there will be described in the following treatise the different devices now in use both as constructed and as contemplated for complete plants, so that any interested person is in position to refer, for comparison with his own conditions, to a plant already built, and to install himself the cheapest possible plant corresponding to his requirements, as well as a regular company would build such a plant for him, and to make the necessary designs, and to form an opinion on plants laid before him.

In regard to forming an opinion on the influence of the water on the boiler material itself, the researches concerning this are not yet concluded; yet it is sufficient in the first place to indicate these influences and to point out the way in which the chemist should proceed in order that not only boiler-scale formation but corrosion as well be prevented. This can only be accomplished by a comparative analysis of the raw water, the purified water, and the water in the boiler; and it is clear that by the higher pressure and by the increasing concentration of the substances, chlorine, sulphuric acid, nitric acid, organic substances, caustic soda, and soda-ash, a destructive action of the concentrated boiler-water on the material of the boiler is made possible. In what manner this corrosion will take place the expert chemist can tell if an extended series of definite observations have been made. The boiler-user will perceive from these comparisons whether the water must be renewed oftener or another water altogether obtained.

The author cannot close these preliminary remarks without expressing his sincere thanks for the assistance he has received in carrying out these researches by the Government Railway, the Emperor Ferdinand's Northern Railway, the Southern Railway Co., the Austrian Northwestern and Southern North German connecting line, the Domain Direct, and the Austrian National Railway Co., which by the sanction to plans have made it possible to test practically several of the devices hereinafter described.

With regard to the plans the engineer of the Prick Company, Herr E. v. Holbling, has been employed with zeal and aptitude, and several of the plans mentioned in Study IX were worked out by him.

EDM. WEHRENFENNIG,
Mechanical Engineer.

VIENNA, January, 1905.

TRANSLATOR'S PREFACE.

The following work was translated first for personal information, but the data contained therein is so practical that the book should prove of considerable value. With its aid the subject of purification and analysis is made plain to even those who are not chemists.

The application of Kalmann's formula affords an easy method for estimating and correcting the treatment in present plants.

The weir system of distributing the water and the displacement system of introducing the lime and soda-ash solutions foreshadow desirable improvements to types of softeners now in use in this country. The experience of the German railroads in water-softening should be of some value to the American roads now generally introducing softening-plants.

While following the German text closely in the reading matter, the translator has taken the liberty of rearranging some parts of the book so that the subjects will follow in a more desirable sequence.

D. W. P.

PHILADELPHIA, June, 1906.

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THE ANALYSIS AND SOFTENING OF BOILER FEED-WATER.

CHAPTER I.

IMPURITIES IN WATER.

Causes of the Pollution of Water.

According to Prof. Hochstetter no water, whether it falls from the air as snow or rain, is completely pure. The rain-water contains the gaseous matter of the air (up to 1/20 of the volume of the water) and carbonic acid (CO_2) (up to 1/110 of the volume of the water), also very often nitric acid (N_2O_5) (in thunder-showers) and ammonia (NH_3) absorbed and dissolved. The oxygen (O) makes the water carried to the earth a weakly oxidizing reagent and the strength in carbonic acid makes it a weak acid.

What this seeping water loses in immediate energy will be replaced by the quantity continually falling and by the unlimited duration of the reaction

Easily soluble rocks or minerals and salts, as rock salt (NaCl), potassium chloride (KCl), sodium carbonate (Na_2CO_3), potassium sulphate (K_2SO_4), sodium sulphate (Na_2SO_4), gypsum ($CaSO_4$), may be entirely dissolved by the seeping water.

100 parts of pure water will dissolve:

Potassium chloride	(KCl)	32.6	parts at 15° C.
Sodium "	(NaCl)	35.7	" " 15° "
Magnesium "	$(MgCl_2)$	30.7	" " 15° "
Potassium carbonate	(K_2CO_3)	24.4	" " 10° "
Sodium "	(Na_2CO_3)	8.3	" " 10° "
Potassium sulphate	(K_2SO_4)	10.3	" " 15° "
Sodium "	(Na_2SO_4)	16.3	" " 18° "
Calcium "	$(CaSO_4)$	.24	" " 21° "

Water containing carbonic acid acts on many rocks and minerals not affected by pure water, especially on the carbonates calcite, dolomite, magnesite, spathic iron ore, which are very slightly soluble in pure water, but are dissolved in large quantities as bicarbonates in water containing carbonic acid, as, for example, calcite as $CaH_2(CO_3)_2$.

100 parts of water containing carbonic acid will dissolve:

Calcite	$(CaCO_3)$	10 to 12 parts	
Dolomite	$(CaMg(CO_3)_2)$	3.1 "	
Magnesite	$(MgCO_3)$	1.2 "	(?)
Spathic iron ore	$(FeCO_3)$	7.2 "	

Also the apparently insoluble compounds—silicates, as feldspar ($K_2Al_2Si_6O_{16}$), mica, which is a silicate of potassium, magnesium and aluminum, hornblende, which contains silica hydrate with aluminum oxide, magnesium oxide, calcium oxide (as well as soda), and usually some iron—may be split up by water containing carbonic acid, especially at high temperatures and high pressure, and held in solution in the form of carbonates and bicarbonates according to their strength in potassium, sodium, calcium, magnesium, manganese, etc.

The water circulating in the ground burdens itself with the dissolved compounds and brings them againt to the surface as component parts of spring-water.

Under the influence of the atmosphere and flowing water the rocks will be loosened, shattered, washed out and worn away and the result of the destruction of the rocks from the action of the atmosphere will be partly chemical where the substances of the rocks will be changed and partly mechanical where the rocks will be dissolved in particles without changing their substance.

Usually both processes occur simultaneously and mutually aid each other. While the chemical changes caused by the atmosphere are effected by the component parts of the air, carbonic acid and oxygen, as well as the water, the water acts simultaneously in a mechanical manner. But the changes in temperature act in the most strongly mechanical manner. Plants act to a smaller degree in aiding the destruction of rocks by the weather.

The wearing away of the rocks under the chemically acting influence of the atmosphere and the water consists of an oxidizing process first and then the formation of hydrates.

Many rocks, as granite, limestone, sandstone, clay which contains small amounts of iron in the form silicon ferric oxide or ferric carbonate and in a free state possess a bluish-gray or greenish color, will become a rusty brown (brown ironstone) when under the influence of the acid ingredients of the atmosphere and iron hydroxide of the water. These changes are accompanied with a loosening and scaly or globular separation of the rocks, which takes place first on the upper surface and continually works deeper into the stratas of the rocks; separated pieces frequently show a brown exterior and an inner undisturbed center of the original color of the rock. Spathic iron-ore deposits (ferric carbonate) are changed by the atmosphere in this manner to limonite (ferric hydrate).

Rocks containing feldspar, as granite, porphyry, trachyte, gneiss, granulite, etc., will be loosened and decomposed into gravel by the decomposition of the feldspar in their inner stratas. The underlying feldspar will be dissolved as orthoclase under the influence of water containing carbonic acid. A kaolinizing process will result, while the alkalies and the limestone of the feldspar will be carried away as carbonate salts, a part of the silica will be liberated in soluble form, and the silicious clay will remain behind as porcelain earth or kaolin. Likewise other silicates, as hornblende, augite, etc., are undergoing a continual wearing away. Olivin will be changed into serpentine by the admission of water and this will be converted into magnesium carbonate and ferric hydroxide by water containing carbonic acid, while the silica will segregate itself in the form of opals or as hydrated silicate of magnesia in the form of meerschaum.

Water containing carbonic acid dissolves the calcium carbonate of limestone as bicarbonate, and by carrying away the latter from dolomitic rocks causes their cavernous structure and their disintegration to powder known as ashes of dolomite or slack.

On the contrary, quartz and mica resist in an extraordinary manner the decomposing influences of the weather, on which account these minerals are mechanically shattered and reduced in size but are unchanged chemically; also the chief part of all sand deposits are made from these.*

The action of the changes caused by the weather, in so far as they have an effect on the loosening of the stratas and bursting open the rocks, are principally aided by the changes of temperature from day to night and of the seasons of the year, to which the outer layers of the earth's surface are subjected. Of all these the most energetic means of breaking up the rocks is the change in temperature by which water is frozen. One volume of water at 0° expands to 1.09 volume of ice on freezing (ice has a density of .9) and exerts in consequence of this an enormous bursting pressure. Therefore the formation of massive heaps of mountains and the numerous blocks in the colder climates and in high mountains, while in warm places there is more often a decomposition reaching far into the earth as a consequence of the chemical action of the seeping water. Lastly, the plants act destructively chemically by the organic acids, which their roots often throw out, and by the carbonic acid, which they yield on dying and decaying, and mechanically by the often irresistible growth of their roots which penetrate the fine layers of the rocks.

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* Water from crystalline mountain formations are the least contaminated chemically, but contain floating particles of mineral or organic origin.

From this literal repetition of Hochstetter's argument it is assumed that the water raised as vapor to the clouds and falling again to the earth by absorption of the gaseous matter in the air or earth, by mixing with water on the ground, already contaminated by dissolving matter changed by the weather and made small and rocks unchanged chemically, and by the decay of organic bodies, at length becomes burdened more or less with foreign matter.

To this argument it must be added that in the earth itself many changes of the salts already dissolved in the water take place. For example, the gypsum and the carbonate of magnesia change slowly into carbonate of lime and sulphate of magnesia, in which the former in the presence of perishable material changes again on account of carbonic acid produced by the latter into bicarbonate of lime. Nitrogenous organic matter produces by decomposition the formation of ammonia compounds or the formation of nitrate salts in the presence of lime, magnesia, or other bases.

Thus a great number of compounds are produced which first occur in the ground and are caused in consequence of changing oxidations or reductions.

If the organic material is sulphurous or is present as pyrites in the ground, sulphuric acid may easily be formed; if iron is contained in the water it readily forms with algæ the often-observed appearance of the so-called iron water, etc.

We differentiate them chiefly as spring-, surface-, or river-water. Most spring- and surface-waters in their course through the earth's stratas take up more or less soluble material; on the contrary, river-water takes up less of such substances, but contains a greater quantity of suspended particles, usually of organic origin.*

Comparing, for example, the spring-water of Kaiserbrunnen in the Semmering district with the flowing water of the Donau and a water from the subterranean watercourses of the Donau (from the vicinity of the North Western railway station), they contain:

The Water contained (in 100,000 parts).	The Kaiser-brunnen.	The Donau, 1878.	The Northwestern Railway Station.
In fixed constituent parts...	13.95 parts	17.21 parts	over 87.21 parts
Calcium carbonate.........	10.31 “	9.79 “	10.16 “
Magnesium carbonate......	1.85 “	3.49 “	19.00 “
Magnesium chloride........	....	....	1.71 “
Sodium chloride...........	.15 part	small trace	5.62 “
Sodium sulphate..........	.17 “	“ “	?
Potassium sulphate........	.11 “	“ “	?
Calcium sulphate..........	.76 “	1.65 parts	25.89 “
Calcium nitrate...........	....	....	22.03 “
Silicic acid................	.18 part	small trace	1.16 “
Organic matter............	.42 “	.56 part	1.70 “

The mountain spring-water of the Kaiserbrunnen is therefore to be designated as very pure; the ground-water from the subterraneous watercourse of the Donau contains very considerable amounts of calcium and magnesia, carbonic acid, and nitric acid.

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* Yet it also occurs, for example, that the tributaries of larger rivers, flowing for considerable stretches through meadows, become highly charged with decaying organic matter and therefore carry carbonic acid holding calcium and magnesia in solution, producing a water which contains much more dissolved material than the water of the main stream. We may not indulge in the illusion that such a water, for example, taken from a tributary of the Donau, fed into a boiler, would only create a small amount of boiler-scale, as if water from the main stream of the Donau were used. Still less may we believe that water from wells dug only a meter away from the river-bed would give a water whose characteristics were similar to that of the river-water. Only from wells which are in direct connection with the river and which are not subjected to muddiness by this connection, continually yield a water whose characteristics are similar to the river-water. If the river-bed of the main stream should be so far away that it is not possible to have a direct connection with the river, it is better in most cases to use a purified well-water, as its composition will be less frequently changed and we will not have to change the chemical additions to it so often.

But ground-water is not alone in being often contaminated to a high degree; spring-water may also contain an extraordinary amount of dissolved matter.

For example, the Lorenz spring of Leukerbad, Switzerland, carries over 200 cu. m. of gypsum ($CaSO_4$) to the surface in a year; the Karlsbad springs carry yearly nearly 6,000,000 kilograms of fixed matter, while the water of the greater rivers contain only 20 parts of fixed particles in 100,000 parts of water according to J. Roth, which are composed of

60.1% carbonates,
9.9% sulphates,
5.2% chlorites, and
24.8% other substances,

such as silica, oxides of alumina and iron, and organic particles.

Artesian-well water similarly often contains large quantities of bicarbonate of soda, besides calcium and magnesia compounds.

In this manner the water takes up a large number and amount of different compounds which often react on one another and form new compounds. For purification chemical means must be used, which must be added to the water in proper amounts, determined by analysis, and clearing-chambers used in which the coarse and heavy precipitates settle by their own weight, and in addition closed filters must be used to remove the finer precipitates, and also by a small velocity of the water flowing through the segregation of the material carried along is accomplished.

Water which at the same time is mechanically and chemically contaminated requires devices for chemical purification and filtration. In general the chemical purification precedes the mechanical and the latter follows after. By specially devised arrangements of the purifying devices and by special design of the system, filters may be dispensed with if the mechanical pollution is enveloped by the flakes caused by the addition of chemicals, and they are carried down with them and completely retained in the apparatus.

In General.

Water purification has the object of making available for use, for boiler feeding, special waters through chemical mixtures and mechanical purification

The pollution of water may come from substances mechanically mixed and from dissolved chemical matter.

The pollution by mechanical mixture may be removed by sedimentation or by filters.

The latter may be natural (sand or gravel banks) or artificial filters (excelsior, coke, sand, charcoal, cellular material, etc.).

The chemically mixed parts consist of minerals easily soluble in water, as gypsum, Glauber's salt, Epsom salt, chlorine compounds, etc., and such minerals as are only soluble in water containing carbonic acid, as limestone, dolomite, magnesia, and iron ore.

In regard to the chemical purification of water the chief consideration is given to those materials contained in water which are precipitated by heat and then form boiler incrustation. The most important of these are the carbonates of calcium and magnesium, as well as the sulphate of calcium.

The quantities of these salts in water may be measured by German degrees of hardness.

A German degree of hardness is the solution of one (1) part Calcium (CaO) in 100,000 parts of water, or a solution containing .01 gram of calcium in one (1) liter of water.*

All mineral mixtures may be calculated with advantage by considering the proportion of their molecular weight to the molecular weight of calcium.

As the molecular weight of calcium bears the proportion to that of magnesia as 56:40, the magnesia contained in water, expressed in German degrees of hardness, may be found by multiplying the grams of magnesia contained in a liter of water by the product $(56/40)\times 100=140$.

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* One (1) French degree of hardness = .01 part $CaCO_3$ contained in 1 liter of water = 1.79 German degrees of hardness.

In the same manner we calculate the bound carbonic acid, in German degrees of hardness, contained in water, by multiplying the quantity in grams contained in one liter of water by $(56/44)\times 100=127$, etc.

Under hardness of water, or total hardness (absolute hardness), is included the sum of the calcium contained as CaO and the magnesia (MgO) calculated to CaO and expressed in German degrees of hardness.

By the older observations, the remaining or permanent hardness was understood that hardness obtained after heating a water so that the carbonic acid was driven off without concentrating the liquid.

By later observations the permanent hardness means that which is communicated to water by the calcium and magnesium compounds not bound by carbonic acid.

The difference between the total hardness and the permanent hardness was called the temporary hardness in the old sense. It is now determined by titrating a measured quantity of water with $^2/_{10}$ normal hydrochloric acid $\left(\frac{2N}{10}\ HCl\right)$ with the use of an indicator and color change.

The difference between the total hardness and the hardness which is obtained by titrating with $^2/_{10}$ normal hydrochloric acid is called the permanent hardness in the newer meaning.

For the estimation of water from the standpoint of its employment for boiler feeding, this hardness must always be influential as opposed to clearness, as the question always depends on the former.

The chemical purification of water is effected by the addition of caustic lime (dissolved calcium) and soda.*

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* Of the barium treatment of Reisert at Cologne no more can be said in this respect than that it first came to the knowledge of the writer during the printing of this work.

The chemical purification of water may be considered accomplished when it shows not more than 10–12 German degrees of total hardness.

If the water has a higher content of lime and magnesia, it should be purified, or the boiler must be operated very carefully and often washed out.

The chemically purified water may contain only a certain per cent surplus quantity of the caustic lime and soda employed for the purification, since from these two materials caustic alkali forms.

The amount of surplus caustic lime or soda, or caustic soda, is called the alkalinity. This is determined by titrating with $^1/_{10}$ normal hydrochloric acid. The number of cubic centimeters of HCl used multiplied by 2.8 gives (very nearly) the content of bound carbonic acid (temporary hardness) in lime degrees in the neutral water.

The alkalinity will likewise be measured in degrees, and at the most should not exceed half the degrees of hardness which the softened water still possesses.

The hardness cannot go below 3 German degrees, as carbonate of calcium is soluble to this extent.

CHAPTER II.

THE ANALYSIS OF WATERS.

1. INSTRUCTIONS FOR THE OBTAINING OF AN AVERAGE SAMPLE OF WATER FOR ANALYSIS.

A WELL-CLEANSED glass flask, preferably with a glass stopper, serves best for a sampling-vessel.

If a cork is used, it must be soaked several times before using, in the water under consideration, or all dirt washed out of it.

In filling the vessel, it must be dipped in the water to be sampled so as to avoid the usual dust and other foreign matter floating on the surface, as well as the muddy bottom.

In every case the flask must be completely filled, emptied again, rinsed out several times with the water, and finally filled as at first.

If the water is pumped from a well, the first water which has stood long in the pipes must be allowed to run off, and sample taken from the later flowing part.

Conduit water must be taken from the conduit and not out of a reservoir.

From flowing streams into which at times waste water from factories enters, similar samples of the water must be taken at different hours for several days, where such pollution is suspected, in filled glass flasks holding 5 to 10 liters, and samples well mixed.

The analysis of water for scale-forming matter by determining the total hardness, the permanent and temporary hardness, the lime and magnesia contents, may be obtained by the engineer himself with the aid of this treatise; the determination of the corrosive matter, on the other hand, must continue to be turned over to the chemical laboratory.

In all questions concerning water an analysis may be employed with advantage.

2. Total Hardness.

The determination of the total hardness may be obtained by Clark's method, an alcoholic titrating soap solution of which 45 c.c. are necessary to satisfy 12 mg. of lime in 100 c.c. of water or to indicate 12° of hardness.

In order to make the first test for this determination take 10 c.c. of the water in a graduated glass cylinder and fill with distilled water to the 100-c.c. mark, giving a 10th part dilution of the water, and then pour this mixture into a shaking-flask. Into this run first 5 or 6 c.c. of soap solution from a burette graduated in 1/10 c.c., shake rapidly, add more soap solution, shake again and repeat the operation, until a thick, strong foam forms, not cheesy, and with lower edge sharply defined, which remains on top of the liquid five minutes practically unchanged and without subsiding. The amount of soap solution used indicates the hardness.

In the beginning allow the soap solution to flow in freely between each shaking; towards the end add by drops .5 to 1.0 c.c. at each time until a small surplus is evident by noting the formation of foam.

The shaking must always take place in the same manner, and it is best to shake up and down, grasping the neck and stopper of the glass with the right hand and the bottom of the glass with the left.

For special investigation of soft water of from 20° of hardness down use 50 or 25 c.c.; for harder waters of more than 20° of hardness use 25 or 10 c.c. of the water to be examined, so that the amount of soap solution which is necessary for the determination of the absolute hardness does not exceed 45 c.c

The necessary amount, which has been determined by this preliminary experiment, is allowed to flow in in this manner, shaking violently after each addition of 5 or 6 c.c. As we near the known point of satisfaction add only 1 to 2 c.c., and when bringing the determination to an end shake after the addition at long intervals of each single drop. So long as the foam is membranous, clotted, or cheesy, the determination of the hardness is not completed, and it will be necessary in such waters to use a greater dilution, of 90 c.c. of distilled water to 10 c.c. of the mixture.

With a water containing magnesia, we must be careful, on account of the quickly resulting transposition of the lime with the fatty acids of the soap forming foam long before the completion of the determination, to continue the titration until the final result is reached. This foam vanishes after standing a while. Its formation indicates the approximate amount of calcium in the water. It is also necessary with water containing magnesia not to conclude the experiment too quickly after the formation of the second foam, as the true result is often given by later shaking. By quickly carrying out the experiment a too small hardness is given, because the chemical reaction and the transposition of the magnesia with the fatty acids of the soap requires time.

According to Prof. C. Blacher of Riga it is advantageous to carry out the determination of the hardness in a neutral warmed condition of the water, and to drive out the free carbonic acid of the water by the blowing in of air.

From the cubic centimeters of soap solution used we may find with the help of the following table the hardness expressed in degrees, which in case of previous dilution is to be multiplied by the coefficient of dilution.

If we have used only 10 to 25 c.c. of water (diluted to 100 c.c.), the degree of hardness indicated is to be multiplied by 10 or 4 respectively.

The use of this table is simple. If you do not find the cubic centimeters of soap solution used indicated in the table,

TABLE GIVING THE DIFFERENT DEGREES OF HARDNESS ACCORDING TO THE QUANTITY OF SOAP SOLUTION USED.

(Faist and Knauss.)

Soap Solution used.	Degree of Hardness.
3.4 c.c.	0.5
5.4 "	1.0
7.4 "	1.5
9.4 "	2.0

The difference of 1 c.c. soap solution = .25 degree of hardness.

11.3 c.c.	2.5
13.2 "	3.0
15.1 "	3.5
17.0 "	4.0
18.9 "	4.5
20.8 "	5.0

The difference of 1 c.c. soap solution = .26 degree of hardness.

22.6 c.c.	5.5
22.4 "	6.0
26.2 "	6.5
28.0 "	7.0
29.8 "	7.5
31.6 "	8.0

The difference of 1 c.c. soap solution = .277 degree of hardness.

33.3 c.c.	8.5
35.0 "	9.0
36.7 "	9.5
38.4 "	10.0
40.1 "	10.5
41.8 "	11.0

The difference of 1 c.c. soap solution = .294 degree of hardness.

43.3 c.c.	11.5
45.0 "	12.0

The difference of 1 c.c. soap solution = .31 degree of hardness.

take the number standing nearest to the left of the cubic centimeter soap solution used and note the hardness expressed in degrees. The difference between the number taken from the table and that found is multiplied by the fraction of a degree of hardness found thereunder, which expresses the difference of 1 c.c. of soap solution. The product so obtained is either added to or subtracted from the degree of hardness first noted, according as the amount used was remote from the figure in the table or vice versa.

Example.—To 20 c.c. of water diluted to 100 c.c. with distilled water has been added 36.2 c.c. soap solution; this indicates 9.35° of hardness, for 36.7 c.c. = 9.5; the difference between 36.7 and the number used, 36.2, is .5, therefore $.5 \times .295 = .15$; $9.5 - .15 = 9.35°$. The absolute hardness of the water is therefore expressed by $9.35 \times 5 = 46.75°$ of hardness, as the water was diluted five times.

According to Prof. Wartha the absolute hardness can be ascertained in the following manner:*

100 c.c. of water with alizarin added as an indicator was heated and titrated with $^1/_{10}$ normal hydrochloric acid, until the beet-red color changed to yellow, and also until on further heating it did not return again.

The number of c.c. of $^1/_{10}$ normal hydrochloric acid used gives the "alkalinity" of the water. Then each cubic centimeter of $\frac{N}{10}$ $HCl \times 2.8$ indicates milligrams of CaO; the number of cubic centimeters of $^1/_{10}$ normal hydrochloric acid used multiplied by 2.7 gives the temporary hardness in German degrees. The neutralized water will now be treated with an excess of a solution composed of equal parts $^1/_{10}$ normal NaOH $\left(\frac{N}{10}\ NaOH\right)$ and $^1/_{10}$ normal Na_2CO_3 $\left(\frac{N}{10}\ Na_2CO_3\right)$, heated several minutes, cooled, filled up to 200 c.c., filtered, and the excess of alkali determined in 100 c.c. of the filtrate by titrating with $^1/_{10}$ normal hydrochloric acid, using methyl orange as an indicator. The number of c.c. of alkali used to satisfy 200 c.c. of the filtrates, multiplied by 5.6, gives the absolute hardness in German degrees.

If the total hardness is less than would correspond to the temporary hardness, this would indicate the sodium carbonate content of the water.

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* Zeitschrift für angewandte Chemie 1902, Heft 9. Critical Study of the Investigation and Purification of Boiler Feed-water, by J. Pfeifer, Private Lecturer, Budapest. (Kritische Studien über Untersuchung und Reinigung des Kesselspeisewassers von Privatdozent J. Pfeifer, Budapest.)

3. Permanent and Temporary Hardness.

The determination of the permanent or remaining hardness meant, after the old style, that given by 100 c.c. of the water tested in a heating-flask and marked by means of a color-line at the surface of the water.

To this sample of water add about 60 c.c. of distilled water, heat, while, to distribute the flame, place the heating-flask on a wire gauze until the surface of the water sinks again to the given mark through the color-line and then filter through a filter-paper dampened with distilled water. Should there not be more than 100 c.c. of the filtrate after this, fill to 100 c.c. with distilled water and proceed as for the determination of total hardness.

As by heating thus to greater concentration the sulphate of lime may be precipitated, care is to be taken that the surface of the water is not allowed to come below the mark. It is important to observe whether the heating vessel has a coating fastened to it, or if a precipitate falls, as by this heating the affinity of the scale-forming matter may be weakened.

In the newer understanding the remaining or permanent hardness is the difference between the temporary hardness and the total hardness. The determination of the temporary hardness is made in the following manner: Add to 56 c.c. of the raw water 2 drops of methyl orange-phenolphthalein solution and then add $^2/_{10}$ normal hydrochloric acid $\left(\frac{2N}{10}\text{ HCl}\right)$ from a burette graduated in $^1/_{10}$ c.c. until the color change takes place from yellow to red. The number of $^1/_{10}$ c.c. of $^2/_{10}$ normal hydrochloric acid used gives the degrees of temporary hardness and therewith the approximate amount of bound carbonic acid.

The most used indicator is methyl orange, which is obtained by the dissolving of 1 gr. in 250 c.c. of alcohol. But a solution of alizarin may also be used for the purpose. In the previous case we recommend the use of methyl-orange, as to the same may also be added phenolphthalein (1 gr. dissolved in 250 c.c. alcohol). This gives us a color indicator applicable with advantage to the following analyses.

4. Determination of the Bound Carbonic Acid, the Magnesia, and the Lime according to Knofler.

Knofler's process * is a titrating process with soap solution similar to the process of investigation we have mentioned; that is, it is known, of the solution used, how many grams of the material are contained dissolved in a liter of the liquid.

Therefore, if we have established by a test the permanent composition of the liquid, we can calculate, on the basis of the chemical equations between the molecular weight and the observed quantity of the solution added, how much of the material to be determined is present in the material analyzed. The completion of the determination will be known by the change of color of an indicator which, according to Knofler, consists of a mixture of phenolphthalein and methyl orange.

These indicators have the property of coloring the water yellow if it has a neutral reaction, but if otherwise to impart either orange or red, if the slightest excess of acid or alkali exists.

Phenolphthalein alone is colorless in acid solution;
“ “ “ red in alkaline solution;
Methyl orange “ “ “ “ acid solution;
“ “ “ “ yellow in neutral and alkaline solution.

A mixture therefore shows in either case an unmistakable color change, passing always through yellow.

For titrating according to Knofler's process we employ a so-called $^2/_{10}$ normal solution $\left(\frac{2N}{10}\text{ solution}\right)$, this solution signifies one which expresses .2 of the equivalent weight of the

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* O. Knofler's Alkalimetry. Justus Liebig's Annals of Chemistry, 1885, Volume 229. (O. Knofler's Alkalimetrie. Justus Liebig's Annalen der Chemie 1885, Band 229.)

acid or base under consideration contained dissolved in one liter. The value of this solution is therefore equivalent to 560° of lime (degrees of lime hardness.)

Knofler recommends $^2/_{10}$ normal hydrochloric acid,
$^2/_{10}$ normal soda,
$^2/_{10}$ caustic soda

in an alcoholic solution.

If the normal hydrochloric acid contained in a liter of water is 36.5 grams, the equivalent weight of the $HCl = 36.5$.

The $^2/_{10}$ normal hydrochloric acid will therefore contain $36.5 \times 2/10 = 7.30$ grams to the liter, and a cubic centimeter contains .0073 gram HCl.

The $^2/_{10}$ normal soda on the other hand contains $53 \times 2/10 = 10.6$ grams to the liter, or .0106 gram per cubic centimeter.

The $^2/_{10}$ caustic soda contains $40 \times 2/10 = 8$ grams per liter or .008 gram per cubic centimeter.

Knofler places 100 c.c. of the water to be tested for its quantity of bound carbonic acid, lime, and total hardness in a beaker, adds to it 1 to 2 drops of indicator, determines the carbonic acid by titrating with $^2/_{10}$ normal acid until the color changes,* places it aside for heating a little more, and titrates with caustic soda in an alcoholic solution, so that it becomes yellow again through the heating, adding only enough liquid caustic soda to give the proper alkaline effect (not so much as to cause the precipitation of lime, or not at the most an excess of 1 c.c.).

Then filter the liquid through a moist filter-paper into a glass beaker. Now add once more $^2/_{10}$ normal hydrochloric acid until the red color shows, indicating that the excess of caustic soda is neutralized and determining the quantity of magnesia.

Then heat it again and add $^2/_{10}$ normal soda solution until a distinct redness appears. It will now again be heated a short time, which will precipitate the lime. If on heating the liquid continues yellow, add a further measured quantity of $^2/_{10}$ normal soda solution to it, and filter the liquid as before through a filter-paper. A small quantity of the clear, red filtered liquid, which must give no precipitate when treated with oxalate of ammonia, is now treated with $^2/_{10}$ normal hydrochloric acid until redness begins again, giving the total lime, while by adding the magnesia found, calculated in degrees of lime, to the total lime the total hardness is found, which can be checked with the determination found with the soap solution. Through this process is known (*a*) the bound carbonic acid, (*b*) the total lime, and (*c*) the absolute hardness, if the various liquids are strictly normal; at the same time, if they are under their equivalent strength, we may, by simple deductions from previous titrations of them, reduce them to terms of $^2/_{10}$ normal HCl and know from the cubic centimeters of NaOH and soda solution used on one side to precipitate the magnesia, iron, and other compounds the cubic centimeters used for the lime on the other.

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* To orange.

If the strength of the solutions has not been fixed exactly, one must rectify the result accordingly

The approximate result, or the rectified number, multiplied by 5.6 gives the corresponding degrees of lime; multiplied by 10.6 it gives the corresponding equivalent quantity of soda-ash in grams in 100 liters of water (if the lime is entirely in solution in the water) as

1 liter normal solution of caustic lime would contain 28 gr. CaO, therefore 1 liter of $^2/_{10}$ normal solution contains 5.6 gr. CaO.

1 liter normal solution of soda-ash would contain 53 gr. Na_2CO_3, therefore 1 liter of $^2/_{10}$ normal solution contains 10.6 gr. soda.

It is convenient to calculate the ascertained amounts of calcium carbonate and magnesium oxide, etc., as lime. This is accomplished by the use of the equivalent weights of the different materials.

For transposing into degrees of lime hardness we have as the equivalent, therefore,

of caustic soda is = 40.
1 lime degree represents 40/28 = 1.43 gr. NaOH
" 100% soda is = 53.
1 lime degree represents 53/28 = 1.89 " Na_2CO_3
" calcium carbonate is = 50.
1 lime degree represents 50/28 = 1.79 " $CaCO_3$
" calcium bicarbonate is = 81.
1 lime degree represents 81/28 = 2.89 " $CaH_2(CO_3)_2$
" calcium sulphate is = 68.
1 lime degree represents 68/28 = 2.43 " $CaSO_4$
" magnesium sulphate is = 60.
1 lime degree represents 60/28 = 2.14 " $MgSO_4$
" magnesium bicarbonate is = 73.
1 lime degree represents 73/28 = 2.61 " $MgH_2(CO_3)_2$
" magnesium carbonate is = 42.
1 lime degree represents 42/28 = 1.50 " $MgCO_3$
" calcium is = 28.
1 lime degree represents 28/28 = 1. " CaO
" carbonic acid is = 22.
1 lime degree represents 22/28 = .786 " CO_2
" magnesia is = 20.
1 lime degree represents 20/28 = .714 " MgO
" sodium bisulphate is = 120.
1 lime degree represents 120/28 = 4.28 " $NaHSO_4$
" iron sulphate is = 139.
1 lime degree represents 139/28 = 4.96 " $FeSO_4+7H_2O$

Take for example a water which has required 4.29 c.c. $^2/_{10}$ normal HCl to change color (from yellow to beginning red), then to which 4.7 c.c. $^2/_{10}$ normal soda is added, and that afterward only begins to redden with .95 c.c. $^2/_{10}$ normal HCl, then the liquid passes clear through the redness by adding 3 c.c. $^2/_{10}$ normal soda-ash showing the alkalinity, and at last is neutralized by means of 1.21 c.c. $^2/_{10}$ normal HCl. Then this water contains, according to Table A, 24° carbonic acid (CO_2), 10° lime (CaO), 21° magnesia (MgO) calculated as lime; or expressed in actual weights, 100 liters of the water would contain

$$24\times .786=18.86 \text{ gr. } CO_2;$$
$$10\times 1 \quad =10.00 \text{ `` } CaO;$$
$$21\times .714=15.00 \text{ `` } MgO.$$

TABLE A.

Titrating Liquid.	Cubic Centimeters Used.	2/10 Equivalent.	Lime Degrees.
2/10 normal HCl.	4.29	×5.6	=24° CO_2
2/10 normal NaOH.	4.70		
2/10 normal HCl.	− .95		
	3.75	×5.6	=21° MgO
2/10 normal Na_2CO_3.	3.00		
2/10 normal HCl.	−1.21		
	1.79	×5.6	=10° CaO

The total hardness of this water is shown to be 21° + 10° = 31°, and this total may be proved by a determination of the total hardness by means of soap solution.

Through these computations of the lime degrees the conception of the proportional amounts of material contained in the water will be simplified, and further calculations rendered unnecessary.

We will therefore always express the proportional quantities in degrees of lime, because this conception of the degrees of hardness is generally accepted and also because it shows the hardness imparted to the water by magnesia.

The rectification of the result, if the titrating liquids are not of standard strength, is very simple, as one need know only the strength of the liquid.

If all three solutions are of standard strength, it requires, for example,

1 c.c. $^2/_{10}$ normal hydrochloric acid or
1 " $^2/_{10}$ " caustic soda or
1 " $^2/_{10}$ " carbonate of soda

for neutralization.

But if, when the $^2/_{10}$ normal hydrochloric acid is tested, the color change occurs first when 1.05 c.c. of $^2/_{10}$ normal sodium carbonate solution is added to 1 c.c. of the $^2/_{10}$ normal hydrochloric acid, the results are changed in the proportion of 1 to 1.05.

In the employment of Knofler's process it is well to observe that the calcium salts are not precipitated by impure caustic soda. If the caustic soda is mixed with soda-ash, which will always be the case in a solution in water, then the caustic soda will take up eagerly CO_2 from the air, which in consequence precipitates the lime by means of the caustic soda mixed with soda-ash. The first thing, therefore, is to use caustic soda without any admixture of sodium carbonate

It is on this account that the soda-lye ($NaOH$) must be used in an alcoholic solution.

As soda-ash is not soluble in alcohol, we must, in case the caustic-soda liquid should take up carbonic acid from the air, remove it from the liquid as a precipitate, and the liquid itself will remain free of soda-ash.

If the material constituting the hardness precipitates a little, it will not essentially change the results. The described process has merited full confidence in practice.

The magnesia may be determined by means of calcium solution in the following manner.

5. Determination of the Magnesia by Means of Lime Solution.

According to J. Pfeifer, Private Lecturer in Budapest, 100 c.c. of heated water having been titrated with $^2/_{10}$ normal HCl with the addition of a mixture of methyl-orange and phenolphthalein according to the determination for hardness of Prof. Wartha, the water, now free from carbonic acid, will be washed out with heated distilled water into a measuring-glass of 200 c.c.; the ascertained total hardness being measured, it is treated with a measured excess (25 to 50 c.c.) of lime-water; the flask is filled 5 c.c. above the mark, closed with a rubber stopper, shaken well, cooled several minutes, and then the liquid passed through a large filter-paper.

Fig. 1

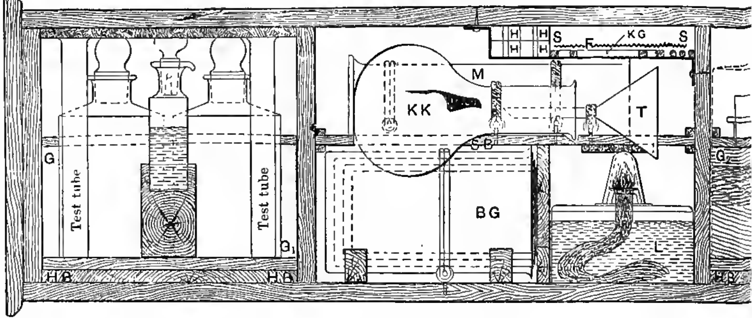


Fig. 2

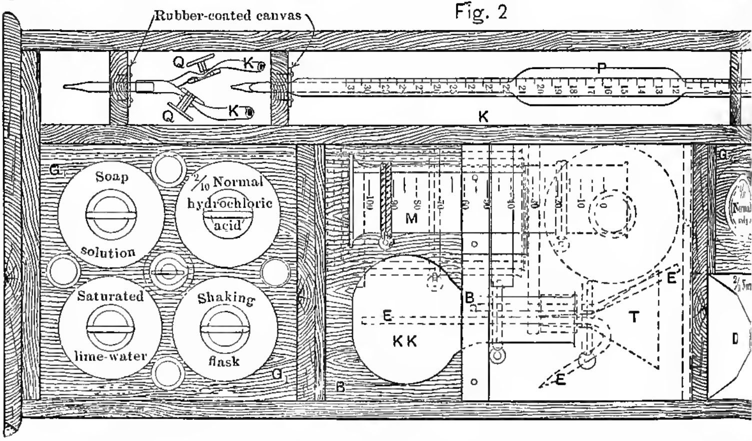


PLATE I

K, place in case for burettes, *G*, place containing 1 flask water, 1 flask with soap solution (Clark), 1 shaking-flask for deter flask with mixture of phenolphthalein and methyl orange (indicato

G_2, place containing 1 flask of 2/10 normal soda-ash solutio soda-lime.

SB, sliding partition with measuring-cylinder (*M*), heating-fl

F, compartment for the burette-holders (*H*), the heating-scree lamp, (*BG*) beakers, (*D*) flask for distilled water, arranged as a wash-

$B_{1, 2, 3, 4}$, burettes for titrating with rubber tubes (*K*), and G_1 and G_2, are sliding wooden cases (*HB*) pressed in from above; bands.

Besides the indicated utensils in the case, which have been paper, 1 small box with ammonium oxalate and 1 meter of rubber water to displace the carbonic acid.

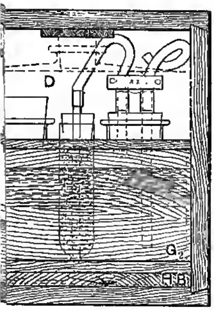


Fig. 3

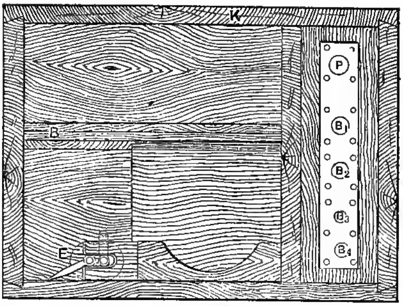
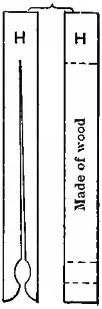


Fig. 4



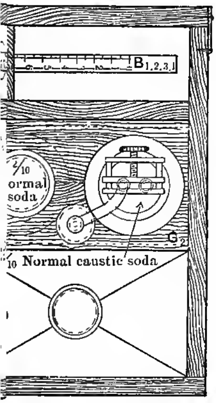
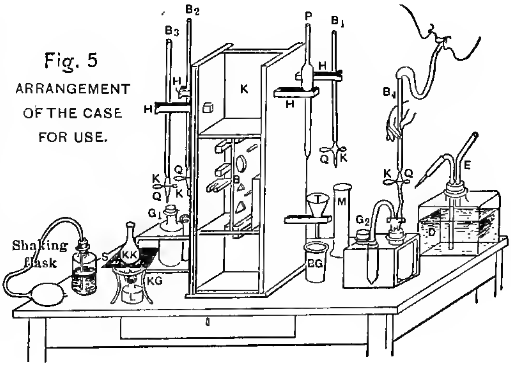


Fig. 5

ARRANGEMENT
OF THE CASE
FOR USE.



I.

of 2/10 normal hydrochloric acid, 1 flask with saturated lime-
rmination of the total hardness with soap solution, 1 dropping-
r), 4 test-tubes.
n, 1 flask of 2/10 normal caustic soda, 1 stoppered pipe with

lask (*KK*), and filtering-funnel (*T*).
reen (*S*), and the separable heating-stand (*KG*). (*L*) spirit-
sh-bottle by the insertion of (*E*).
pinch-cocks (*Q*). *P*, pipette of 25 c.c. capacity. The places
he glass utensils in the middle space are held down by elastic

given letters, there is contained 1 towel, turmeric paper, filter-
tubing, 1 rubber bulb with rubber tube for blowing air in the

[*To face p. 23*]

In 100 c.c. of the filtrate the excess of lime will be measured back, and from the lime used the magnesia is calculated.

Care should be taken that in the determination of the hardness, as well as in that of the magnesia, a sufficient surplus of the precipitant be employed. The lime solution must go through a correspondingly accurate determination, and its strength proved by the following method: 56 c.c. of the solution is placed in a stand-glass, colored with a mixture of methyl-orange and phenolphthalein, and titrated long enough with 2/10 normal HCl from a burette divided into 1/10 c.c., until the color change from red to yellow results.

The number of 1/10 c.c. of $^2/_{10}$ normal HCl gives approximately the strength of the lime solution in degrees, and if this strength in degrees is multiplied by .4 we have thequantity of magnesia in milligrams.

6. TRAVELLING-CASE.

Figs. 1 to 5 represent a hand-case useful for travelling from place to place, made from the author's plans, by Von Rohrbeck's Successor, No. 59 Karntnerstrasse, Vienna 1. In this are contained all the liquids, such as soap solution, $^2/_{10}$ normal Na_2CO_3, $^2/_{10}$ normal NaOH in an alcohol solution, $^2/_{10}$ normal HCl, lime-water, indicators, distilled water, and all implements, such as measuring-cylinders, heating-flasks, beakers, funnel, spirit-lamp, brushes, etc

The case is likewise a titrating, filtering, and heating stand.

The caustic-soda solution is fully protected against the entrance of carbonic acid from the air.

The lime solution can be easily renewed; it is kept in a common glass-stoppered bottle.

CHAPTER III.

PREPARATION OF THE NECESSARY CHEMICALS FOR WATER ANALYSIS.

Titrating Soap Solution.

For the preparation of the soap solution soak 150 parts of lead plaster (*Emplastrum Lithargyri simplex*) on a water-bath, add 40 parts of pure potassium carbonate, and triturate to a uniform mass. Treat the latter with strong alcohol, allow it to settle, filter, distil the spirits of wine from the filtrate and dry the soap residue in a water-bath.

Dissolve 20 parts of the potash soap thus obtained in 1000 parts of diluted spirits of wine having a specific gravity of .9213, take 100 c.c. barium-chloride solution in a stoppered flask and allow soap solution to flow into it until after shaking a thick foam occurs which maintains itself for five minutes at least on the upper surface of the liquid.

If the soap solution is properly prepared in the manner given above, it will require less than 45 c.c. to 100 c.c. of barium chloride. After having ascertained by a second experiment the value of the soap solution against the barium chloride solution for a certainty, dilute the soap solution with spirits of wine of the above specific gravity until exactly 45 c.c. are required to produce the foam described in 100 c.c. of barium chloride.

Chloride of Barium Solution for Testing the Soap Solution.

Dissolve .523 gram of pure dried crystallized barium chloride ($BaCl_2 + 2$ aqua), which is a quantity corresponding to .120 gram of calcium, in 1 liter of distilled water. 100 c.c. then contains 12 milligrams of calcium, also an amount of barium chloride equivalent to 12 German degrees of hardness.

Caustic Soda in an Alcoholic Solution.

As caustic soda is soluble in alcohol, but soda-ash is insoluble, a solution is obtained free from soda-ash for the precipitation of the magnesia, oxides of iron, and alumina, and by whose use no calcium is precipitated, in the following manner:

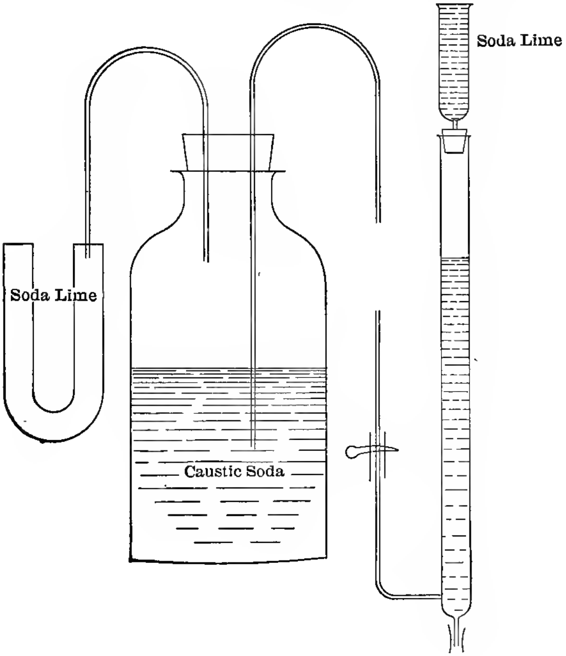


FIG. 1.

Dissolve pure caustic soda in the least possible water or dissolve 8 grams of caustic soda in about 4 to 5 c.c. of lukewarm water.

To this add a determined volume of absolute alcohol and warm for 2 to 3 hours in a reflex cooler with the help of a water-bath, cool off, stopper, and allow to stand in the cold.

By this all the carbonates precipitate themselves to the glass sides.

Filter the clear solution rapidly through a folded filter.

Keep the liquid for use in the previously described apparatus.

2/10 Normal Hydrochloric Acid.

Place 7.30 grams of pure concentrated hydrochloric acid in a small beaker and dilute with distilled water up to 1 liter. One c.c. of this liquid must contain .0073 gram of HCl as shown by titration with $n/10$ silver solution after neutralizing the acid with soda solution and with potassium chromate as an indicator.

2/10 Normal Soda Solution.

Dissolve 10.6 grams of pure carbonate of soda (Na_2CO_3), freed of water, in 1 liter of water.

The removal of the water is easily accomplished by heating the finely powdered sodium carbonate to red heat in a porcelain crucible, allowing it to cool in a desiccator, and then taking the necessary quantity.

One c.c. of this solution then contains .0106 gram Na_2CO_3.

Indicators.

1. Methyl orange (dimethyl-anilin-azobenzene-sulphonate). Dissolve 1 gram of this substance in 1 liter of distilled water. The resulting orange-colored liquid will be made red by mineral acids and yellow by alkalies. Carbonic acid does not affect it. The indicator is uselesss in the presence of compounds alkaline with ammonia.

2. Phenolphthalein. Dissolve 1 gram in 100 c.c. of 98% alcohol. It will be made violet-red by alkalies and colorless by acids.

Equal portions of 1 and 2 are mixed for the preparation of the indicator previously described in this work.

3. Alizarin will be made beet-red by acids. In a neutral condition it is yellow in color.

Preparation of the Lime-water.

Cover freshly burnt lime with distilled water and after settling add as much water as will form a dilute milk of lime, fill a flask with the latter, shake well and allow it to settle.

Preserve the clear liquid, the lime-water, in a well-closed flask (which should preferably have a rubber cork).

The lime-water must color red litmus paper blue, turmeric paper dark brown, and give a strong precipitate with sodium carbonate. If this should no longer be the case, the lime-water will have been spoiled by the action of the air.

The determination of the strength of the lime-water in terms of calcium is made by titrating 56 c.c. of the filtered lime-water with $^2/_{10}$ normal HCl.

The number of $^1/_{10}$ c.c. of $^2/_{10}$ normal HCl used gives the number of degrees of hardness.

Determination of the Chlorine.

As it is often necessary to know the quantity of chlorine occurring in the water, whether in the form of chlorides or free acid, or the quantity of combined or free sulphuric acid, for the easiest analytical method of determination of both ingredients we recommend those given in the following from Tiemann-Gartners Handbuch zur Untersuchung und Begutachtung von Wassern.

In both determinations it is advisable to test whether greater or less quantities of the ingredients are present in the water. According as this is the case, we take, if more, 100 c.c., if less, 500 c.c., and evaporate it until approximately to 100 c.c. We may now proceed with the examination.

For the preliminary test neutralize with dilute nitric acid, using one drop of methyl orange as an indicator until a weakly acid reaction is shown, and then add several drops of sodium carbonate solution thereto until the acid reaction is destroyed. The solution must in no case have an acid reaction, but rather have an alkaline one. Now treat the solution with approximately 3 to 4 drops of a solution of netural chromate of potassium (K_2CrO_4) and titrate with the following silver solution until a red color is obtained, which may be accomplished satisfactorily after some practice.

From the number of cubic centimeters used calculate the quantity of chlorine which was in the sample tested.

Preparation of n/10 Silver Solution.

Dissolve 17,000 grams of pure fused silver nitrate ($AgNO_3$) in 1 liter of water and when necessary filter through a dry filter-paper into a well-sealed flask made of dark glass. Each cubic centimeter of this solution corresponds to .00355 gram of chlorine, .00365 gram of HCl or .00585 gram of $NaCl$.

As an indicator in carrying out the titration with silver solution a cold saturated solution of pure chromate of potash (K_2CrO_4) is to be used.

Determination of the Sulphuric Acid.

For this determination boil as in the determination of the permanent hardness (page 16) and fill with distilled water to the original volume. By this boiling a sample is obtained approximately free from the bicarbonates (carbonates) of the earthy alkaline metals, which to a large extent tend to injuriously affect the determination, while by the repeated filling with distilled water a precipitation of the gypsum is prevented.

Heat 100 c.c. of the prepared water to boiling in a flask which has a mark at 150 c.c., and add 10 c.c., or in highly sulphuric acid waters 15 to 20 c.c., of the barium chloride solution given on page 30. Heat several minutes and then allow as much of the equivalent potassium chromate solution described on page 30 to flow in as will color the liquid standing above the precipitate a faint but precipitable yellow.

After cooling the liquid fill with distilled water to the mark, shake up, and filter through a dry filter-paper.

Place 100 c.c. of the filtrate in a tall cylinder of colorless glass which the quantity of liquid will fill to a height of 15 to 20 cm. Then treat 100 c.c. of distilled water in a similar cylinder with as much of the potassium chromate solution as will give a similar color as the previous test.

The excess of potassium chromate solution dete mined in this way multiplied by $^3/_2$ will give the potassium chromate solution used originally for titrating back. The resulting difference in cubic centimeters of the potassium chromate subtracted from the cubic centimeters of barium chloride solution used gives the true number of cubic centimeters of barium chloride solution which was necessary for the precipitation of the sulphurous acid (SO_3). This difference multiplied by 4 gives the parts of sulphurous acid (SO_3) present in 100,000 parts of water.

Example.—100 c.c. of boiled water was treated with 15 c.c. of barium chloride solution. 5 c.c. of potassium chromate solution sufficed for the precipitation of excess of barium chloride added.

Now it was filled to 150 c.c. and filtered. 100 c.c. showed the same color as 100 c.c. of distilled water to which we had added .6 c.c. of $^1/_{10}$ potassium chromate solution.

$$.6 \text{ c.c.} \times {}^3/_2 = .9 \text{ c.c.} \qquad 5 \text{ c.c.} - .9 \text{ c.c.} = 4.1 \text{ c.c.}$$

$$15 \text{ c.c.} - 4.1 \text{ c.c.} = 10.9 \text{ c.c.}$$

100,000 parts of water therefore contains

$$10.9 \times 4 = 43.6 \text{ parts of sulphurous acid } (SO_3).$$

n/10 Barium Chloride Solution for the Quantitative Determination of the Sulphurous Acid.

($^1/_{10}$ normal barium chloride solution.)

Dissolve 12.2 grams of pure dry crystallized barium chloride ($BaCl_2+2H_2O$) in distilled water and dilute to 1 liter.

n/10 Potassium Chromate Solution for the Quantitative Determination of Sulphurous Acid.

Dissolve 7.365 grams of chemically pure dry potassium chromate in a liter flask in about 100 c.c. of distilled water. To this add, a drop at a time, liquid ammonia until the red color of the solution turns into a pure yellow and exactly neutral ammonium potassium chromate is produced. After this takes place fill the liter flask exactly up to the mark. Equal volumes of this solution and the *n*/10 barium chloride solution mixed together must not be colored after the precipitate has settled, and the clear liquid standing above the precipitates must produce no cloudiness with dilute sulphuric acid, which shows both solutions must be exactly equivalent to each other.

CHAPTER IV.

THE IMPROVEMENT OF WATER.

The mud and scale-forming matter can be restricted, if not entirely removed,

1. Through filtering the water.
2. Through preheating the water and frequently blowing down and washing out the boiler, or
3. Through the rapid precipitation of the scale-forming matter in the boiler itself and blowing out and washing out the precipitate, or
4. Through condensation of the steam and using again the waters thus obtained, and finally
5. Through purification of the water before its employment (through so-called purifiers).

For stationary and marine boilers all five methods may be used; for locomotive boilers method number 4 can of course not be used, and the two methods of preheating are applicable only where the quantities of impurities are small. Here the only thing to be done is to blow out and wash out the precipitates of the scale-forming matter from the boiler itself and the tender or the reservoir at the water-stations.

The periods between blowing down and washing out show whether the priming and foaming arises from having too few water-changing stations. The determination of the means for the precipitation of the scale-forming matter in the boiler or for purification before use can only be done by the advice of a chemist, but almost any railway engineer can do it himself by following this treatise.

1. Filtration of Water.

Purification by Filters.—The mechanical pollution can be removed only by allowing a long time for settlement or taken out of the water through artificial or natural filters. The best filters are the sand or gravel banks of bottoms. The longer the polluted water flows through and the greater they are, the better is the purification. Ground-water which flows through natural filters is therefore almost entirely clear; surface-water, on the contrary, is more or less turbid and impure.

Artificial filters are composed of gravel, quartz, sand, coke, charcoal, felt, linen, excelsior, sponges, asbestos, etc. The greater the cross-section of the filters, and the less the speed of the water passing through, the easier the removal of the pollution; on the other hand, the less the necessity of making up loss of filtering material on account of the necessary washing, just so much more efficient and economical is the filter. A sand filter is shown in Fig. 2.

Amongst the sand filters belong the Reisert filter * (Fig. 3), which operates by means of air, steam, and water currents; the Krohnke filter † (Figs. 4, 5, 6, 7), in which the filter-sand is stirred up by means of mechanical rotation while a stream of water is passed through it. A modification of this is represented in Fig. 6, a filter designed by the author; it is operated by air and a stream of water, without steam, and in which the area of the circle is agitated by the obliquely placed stirring-arm disturbing the sand over the entire cross-section.‡ The capacity of all these filters depends on the condition of the water and should not exceed a rate of flow of 8 cubic meters per hour per square meter of filter surface.§ For this a head of

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* See Eisenbahntechnik der Gegenwart, Vol. II, Fig. 753.

† On the Aim and Operation of Filters for Water Purification, Von Mallenbach, Hamburg, Halle a. S., published by Carl Marhold, 1900. (Ueber Zweck und Ausführung der Filter bei Wasserreinigungsanlagen.)

‡ See page 34. Austrian patent granted.

§ See Eisenbahntechnik der Gegenwart, Vol. II, Fig. 753.

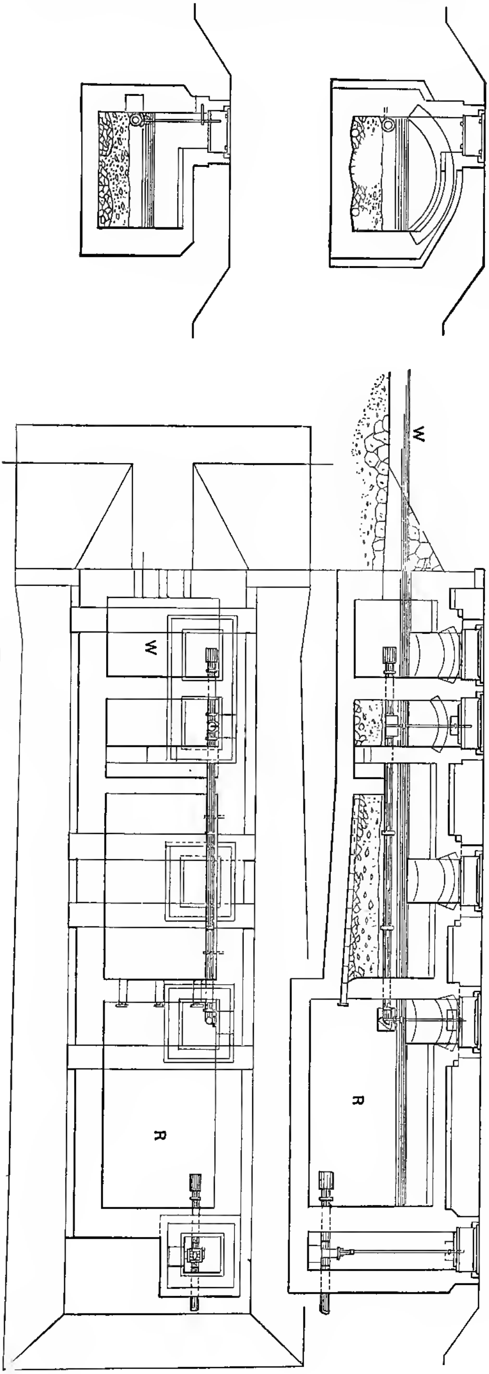

FIG. 2.

.5 to 2 meters is necessary. The necessary water for washing may be estimated as 4% of the water required.

Dehne uses an inserted filter-press, *F*, in which the impurities of the water are held back by cloths and which are removed through openings of the press from time to time (Fig. 9).

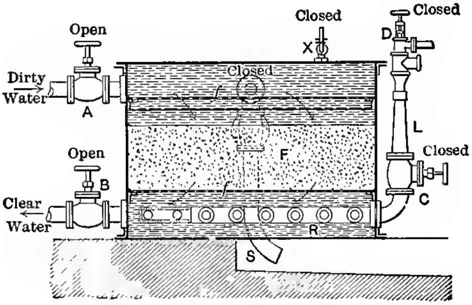

FIG. 3.

Klein's filter is similar (see Fig. 10).

We have not yet mentioned a filter in which the washing takes place by streams of water through the sand while

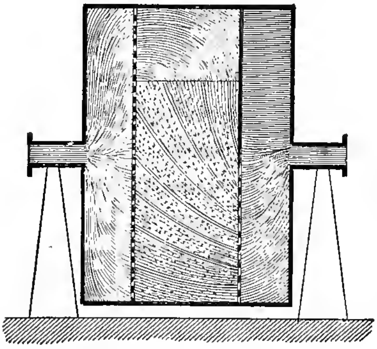

FIG. 4.

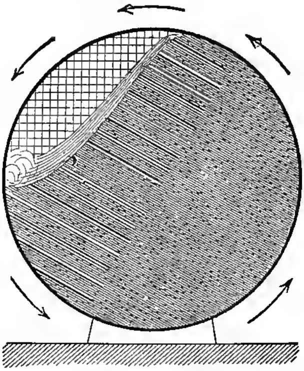

FIG. 5.

mechanically stirred up (Fig. 11) or the open filters where rakes passing through the bed of sand are moved to and fro (see Fig. 134, page 225). Excelsior filters are largely selected on account of the cheapness with which they may be made and on account of the saving in wash-water. A combined

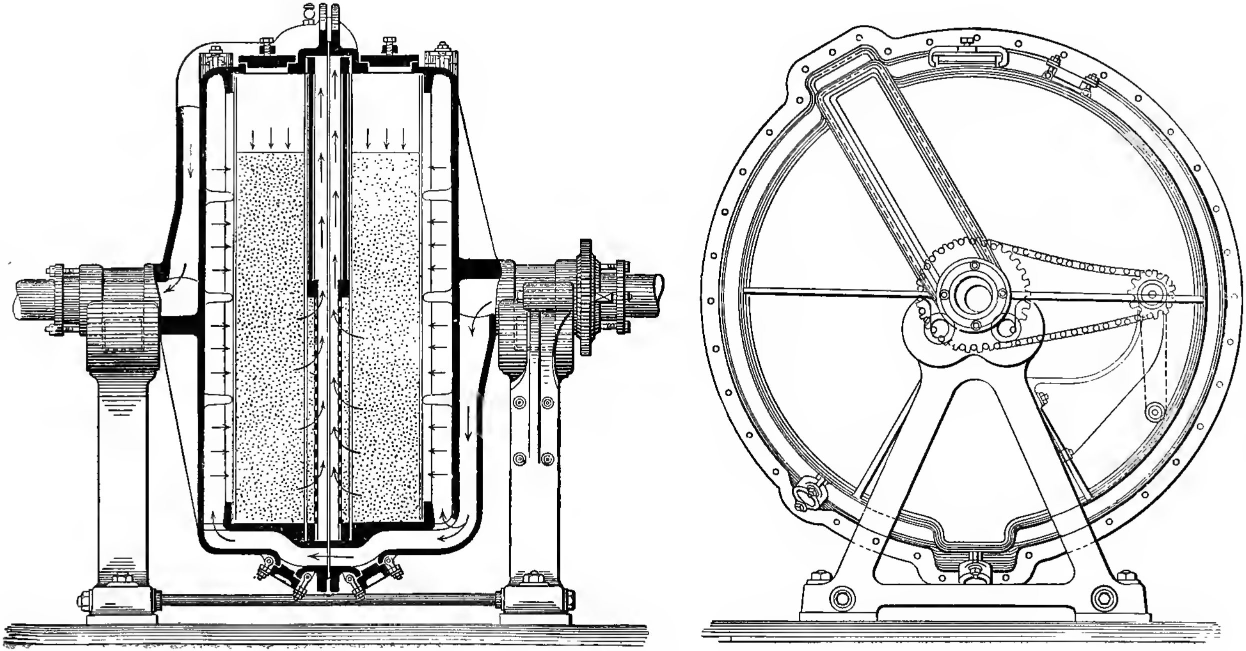

Fig. 6.

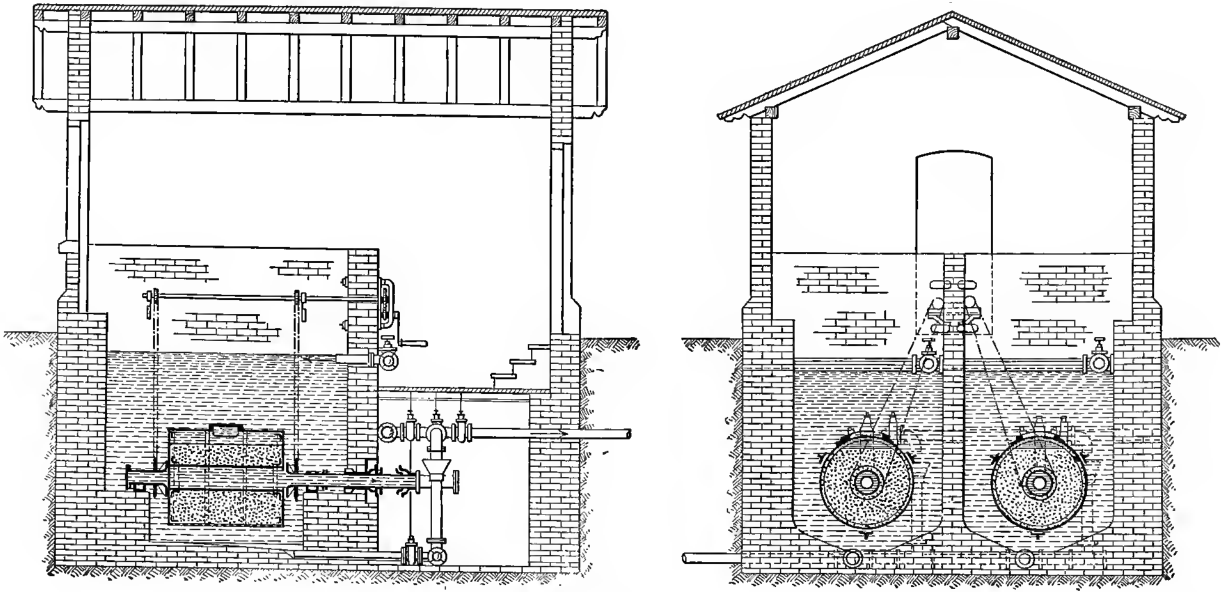

FIG. 7.

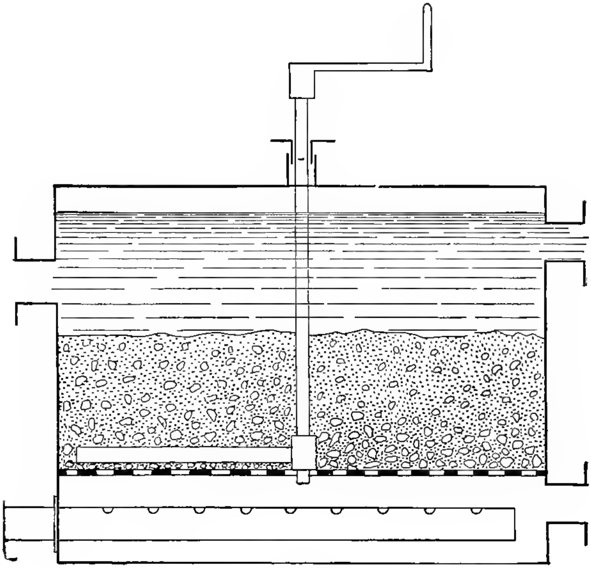

Fig. 8.

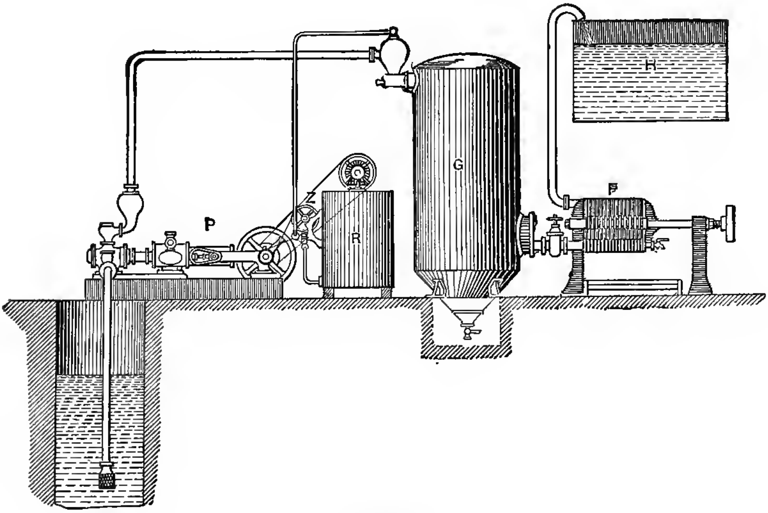

Fig. 9.

filter of sand and excelsior is also much used. The current of water in excelsior filters always passes upward.

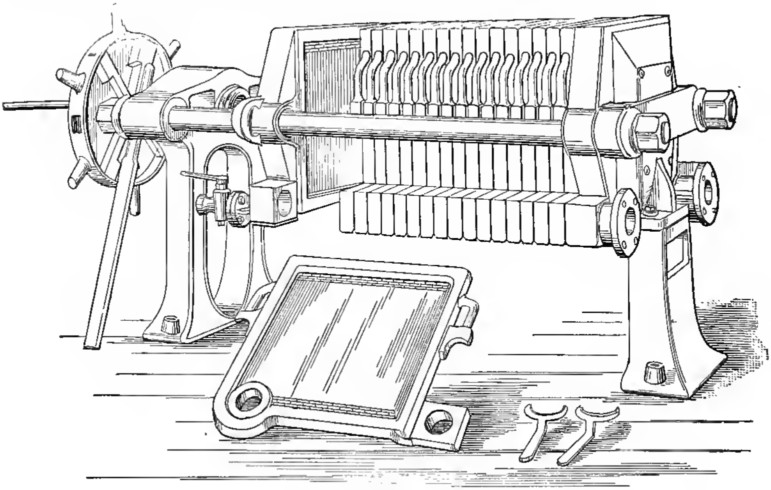

FIG. 10.

Often these do not filter the water clear enough; then a suitable precipitant is needed, which is mixed through the

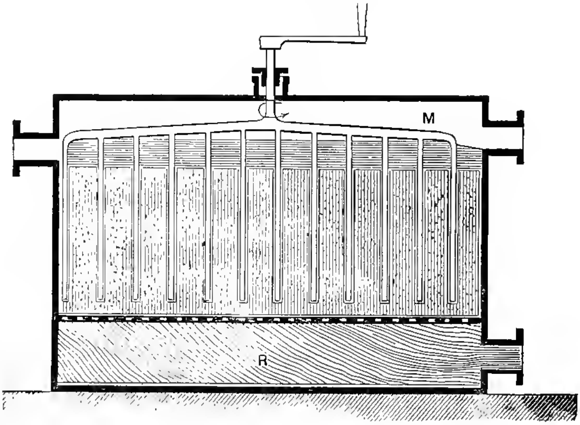

FIG. 11.

water in a special distributing chamber and is added as a solution in proportions corresponding to the water being purified.

These precipitants act chemically and mechanically at the same time. Their advantage consists in that they form large flakes; the small ones, floating in the water as colloidal matter, are hard to filter and therefore cause clogging. The partly purified water then goes through the filter, and burdens this with only a small quantity since so little matter remains in suspension.

The coagulants used are as follows: lime-water with alum, lime-water or caustic soda with chloride of iron or iron sulphate. The latter iron salt has been used extensively, as the oxyhydrate of iron precipitated is heavy and in large flakes.

Lime-water or milk of lime alone may be used if the water contains carbonic acid, because they combine with each other, forming precipitating flakes of the suspended matter.

2. Preheating the Water.

Water which contains principally carbonate of lime may be improved by simply heating, as then the carbonate of lime is thrown down in the heater and not carried into the boiler. However, a preheater is applicable only where the amount of water handled is small.

For larger quantities of water, such as at the railway water-stations, it is not applicable. The preheaters are very necessary for waters which contain bicarbonate of magnesia. Such waters react very slowly with the additions prescribed for chemical water purification, so that without preheating only a slight softening will be obtained.

3. Precipitation in the Boiler.

Precipitation in the boiler itself may be employed where one must avoid the cost of a more elaborate arrangement, where the water cannot be improved by warming, and one is not compelled to be frugal.

Such precipitation of the water may be undertaken where the latter contains carbonate of lime, carbonate of magnesia, or sulphate of lime, and where it is easily reached, and therefore may be easily removed by blowing down and washing out the precipitate thrown down.

The greatest accumulation of these precipitates occurs in an appliance serving as a mud-collector, which automatically takes out a part of the flaky particles rising to the surface after the action of the compound, and before these become thicker and sink to the bottom. There are various makes of these slime-catchers, among them those of Von Schroter, Derveaux, Grimme, Natalis & Co., Lindemann, etc., from which the accumulated precipitates are blown out from time to time.

Where such slime-catchers are not at hand, the precipitate found in the body of the boiler is removed by means of simply washing out through the blow-off.

Neither by the employment of slime-collectors nor by simple blowing out of the boilers to the bottom while quiet is it possible to remove the slime so as to keep the boilers sufficiently free from boiler-scale.

The fact is that, on the one hand, not all the precipitates contained in the boiler go into the mud-catcher, but a portion goes through this before the reaction is completed. On the other hand they may deposit themselves beyond the scope of action of the blow-off and will not be carried along by the water rushing out.

In either case a large part of the precipitate will remain behind in the boiler; but all these precipitates, it is unnecessary to say, bake fast on heating the boiler-water.

It must also be pointed out that, if one decides on precipitation in the boiler, it is not a matter of indifference what compound is used.

If a water principally containing bicarbonates is used, no caustic lime may be taken for a precipitant, for by this the quantity of precipitate in the boiler would be doubled. Where water contains principally gypsum, soda-ash should be used as a compound; in water which contains bicarbonates of alkaline earths and gypsum, etc., we will use caustic soda or soda-ash or operate with silicate of soda.

At one time the bichromate of soda was brought into use as boiler compound.* This precipitated the lime salts as chromate of lime and decomposed the magnesium salts. It will be apparent that by this substance a large quantity of precipitate was thrown down in the boiler itself, which clogged up the spaces between the fire-tubes.

In using the various compounds mentioned above, preliminary experiments must always be made to ascertain whether they should be added gradually or at one time, to determine if they do not fill the feed-pipes with precipitate, and lastly to note if they cause foaming in the boiler-water.

These investigations must define the known limits, and the manner and method of the action of the compound on the scale-forming matter must be known.

Under the head of "Purification of Water" the operation of these means will be described.

For small plants, where no very great quantity of water is evaporated, one may use, according to Prof. A. Rossel (see his brochure, "The Purification of Feed-water for Steam-boilers. Winterthur: Press of Moritz Kieschke"), as much soda-ash in the steam-boiler as will throw down the dissolved salts as precipitates but not as incrustation.

By this treatment the lime of the bicarbonates of lime will fall as granulous precipitate; in the same manner the bicarbonate of magnesia will be broken up and come down as magnesium hydroxide.

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* Chrome salts. If we adopt the simple equations given in the earlier pages, 2.62 kg. of pure or 3 kg. of commercial chromate of soda ($Na_2Cr_2O_7$) is necessary for the breaking up of 1 kg. of calcium carbonate + 1.36 kg. calcium sulphate, which at a gross price of $19.20 per 100 kg. corresponds to an expenditure of 68 cents. The same work is accomplished with 1 kg. of commercial caustic soda, which, at $5.76 per 100 kg., costs only 6 cents, or one tenth of the above. The chrome salts are therefore too dear for use as boiler compounds and besides are poisonous.

In both cases the soda added to the water regenerates itself again and again, in consequence of the heating of the water liberating the carbonic acid.

If sulphate of lime (gypsum), nitrate of lime, calcium chloride, sulphate of magnesia, or chloride of magnesia is present, a complete breaking up and precipitation of these salts will take place, but for each new quantity of these salts entering the boiler a corresponding quantity of soda-ash must be added, whilst the quantity of soda-ash for the bicarbonates is always drawn again from the boiler itself and does not have to be replaced. Rossel's method is used by Von Reichling in Dortmund and is there known also under the head of Von Reichling's Method.

With the exception of bichromate of soda all the materials employed for precipitation are precipitants. The bichromate of soda is at the same time a precipitant for lime and a solvent for magnesia; it can therefore be used where the purity of the water and steam does not matter and the water contains much magnesia. But it will cause all the annoyances of other precipitants by the existence of lime salts in the water. It is still questionable if the chromate of magnesia compounds are not broken up under certain conditions of the operation of the boiler and if the chromic acid set free attacks the boiler-plates.

All secret compounds which act injuriously on the boiler-shell or bring further impurities into the boiler are objectionable, and in every case are too dear when soda-ash, their chief component, is so cheap.

The societies in Munich have earned themselves great credit in the struggle against these secret compounds, the results of whose investigations were published openly in the Breslau issue of the Proceedings of the Society of Chief Boiler Inspectors.

A great number of such remedies were analyzed by the Official Chemist of the Grand-duchy of Baden in Karlsruhe and by the Chemical Laboratory for the Investigation of Heat at

TABLE B.—CHARACTERISTICS AND PURIFICATION OF FEED WATERS.

			1	2	3	4	5	6	7
I.	Material occurring in the water:		Nitric Acid; Sulphuric Acid; Bicarbonate and Carbonate of Calcium and Magnesia.	Magnesium Chloride.	Oxides of Iron and Aluminum.	Calcium Bicarbonate.	Bicarbonate of Calcium and Bicarbonate of Magnesium.	Sulphate and Nitrate of Calcium.	Calcium Chloride and Magnesium Chloride.
II.	Scale formation due to the presence of the above material in water:		Sulphate of magnesia: No. Nitrate of magnesia: No. Bicarbonate of magnesia } Yes. Carbonate of magnesia } Yes.	Yes. At and above 4 atmospheres (58.8 lbs.)	Yes.	Yes.	Yes.	Sulphate of calcium: Yes. Nitrate of calcium: No.	Calcium chloride: No. Magnesium chloride: Yes. At and above 4 atmospheres (5 lbs.).
III.	Solubility and amounts of the substances in natural water:		Nitrate and sulphate of magnesia and magnesium chloride are very easily soluble. Carbonate of magnesia is soluble with difficulty up to 17 degrees of hardness. Bicarbonate of magnesia is considerably more soluble. Magnesium oxide is soluble with great difficulty up to 2.5 German degrees of hardness.		Only a small amount of these compounds are contained in natural waters.	Carbonate of calcium is soluble up to between 2 and 3 German degrees of hardness. Calcium bicarbonate is considerably more soluble up to 65 German degrees of hardness.	Calcium bicarbonate is soluble up to 65 German degrees of hardness. Magnesium bicarbonate is considerably more soluble.	Sulphate of calcium is soluble at: 0° C. 1 part in 415 parts water; 18° C. 1 " " 386 " " 99° C. 1 " " 451 " " At 140° C. it is completely precipitated from the water. Nitrate of calcium is much more soluble.	Very easily dissolved.
IV.	Means of causing precipitation and transposition:	Cold.	*a.* Caustic soda or lime (CaO). Caustic soda is easily soluble in water. Caustic lime is soluble with difficulty, as 1 part of burnt lime (CaO) dissolves itself in 800 parts of water. In hot water and after standing a long time the solubility of the caustic lime decreases still more. Saturated lime-water has about 130 German degrees of hardness.				*a.* Carbonate of soda (soda ash).		
		When hot.	*b.* By heating alone without precipitants.	*c.* Heating alone at high pressure without precipitants.	*b.* Heating alone without precipitants.	*b.* Heating alone without precipitants.	*b* Heating alone without precipitants.		*b.* Heating with soda ash.
V.	Procedure:		*a.* $Mg(NO_3)_2 + 2NaOH = Mg(OH)_2 + 2NaNO_3$. $MgSO_4 + 2NaOH = Mg(OH)_2 + Na_2SO_4$. $MgH_2(CO_3)_2 + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$. $MgH_2(CO_3)_2 + 2NaOH = Mg(OH)_2 + 2NaHCO_3$. $MgCO_3 + 2NaOH = Mg(OH)_2 + Na_2CO_3$. $MgCl_2 + 2NaOH = Mg(OH)_2 + 2NaCl$. *b.* By heating under pressure $Mg(OH)_2$ precipitates from the carbonate of magnesia compounds and they evolve carbonic acid. *c.* $MgCl_2$ dissociates under pressure of 4 atmospheres and heat into $Mg(OH)_2 + 2HCl$. *d.* A breaking up of $MgSO_4$ by heating under high pressure is probable but is not known for certain.		*a.* By means of caustic soda or caustic lime the oxides of iron and alumina will be precipitated as hydroxide of iron and alumina. *b.* Carbonate of iron compounds allow the iron to precipitate as hydroxide of iron on heating.	*a.* $CaH_2(CO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O$. $CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$. *b.* By heating without precipitants: $CaH_2(CO_3)_2 = CaCO_3 + H_2O + CO_2$.	*a.* $CaH_2(CO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaHCO_3$. The bicarbonate of soda transposes $2NaHCO_3 = Na_2CO_3 + H_2O + CO_2$ $MgH_2(CO_3)_2 + Na_2CO_3 = MgCO_3 + 2NaHCO_3$, and as above $2NaHCO_3 = Na_2CO_3 + H_2O + CO_2$. *b.* $CaH_2(CO_3)_2 = CaCO_3 + H_2O + CO_2$. $MgH_2(CO_3)_2 + 2H_2O$ heated under a pressure of 4 atmospheres (58.8 lbs) gives $Mg(OH)_2 + 2H_2O + 2CO_2$.	$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$. $Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$.	*a.* $CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$. By heating the transposition tak place more actively than when in cold condition. *b.* $MgCl_2 + Na_2CO_3 = MgCO_3 + 2NaCl$
VI.	There remains in solution after the precipitation or transposition occurs:		Nitrate of soda. Sulphate of soda. Carbonate of soda.	Chloride of soda. Carbonic acid. Hydrochloric acid.	Sulphate of soda. Carbonate of soda.	As $CaCO_3$ is very soluble in water very little of the above-mentioned material remains in it.	Regenerated soda ash ready for further transposition with fresh quantities of bicarbonates and the existing carbonic acid.	Sulphate of soda. Nitrate of soda.	Sodium chloride.
VII.	There is present in the precipitate after the precipitation occurs:		Magnesium hydroxide.		Aluminum hydroxide. Iron hydroxide. Calcium carbonate.	Calcium carbonate.	Calcium carbonate as sludge. Carbonate of magnesia in so far as it is insoluble, and as the solubility is destroyed it exists finally as magnesium hydroxide.	Calcium carbonate.	Calcium carbonate.

$MgCO_3$ changes itself according to columns 1 and 2 under high pressures in the boiler into $Mg(OH)_2$ and CO_2.

1 gram CaO is equivalent to 1.43° NaOH = 1.79 grams $CaCO_3$ = 1.49 grams $MgCO_3$
1.89° Na_2CO_3 of 100% = 2.57 " $CaH_2(CO_3)_2$ = 2.28 " $MgH_2(CO$
2.11° " " 90% = 2.43 " $CaSO_4$ = 2.14 " $MgSO_4$.

TABLE B.—CHARACTERISTICS AND PURIFICATION OF FEED WATERS.

3	4	5	6	7	8	9
of Iron and luminum.	Calcium Bicarbonate.	Bicarbonate of Calcium and Bicarbonate of Magnesium.	Sulphate and Nitrate of Calcium.	Calcium Chloride and Magnesium Chloride.	Bicarbonate of Soda (neutral reaction).	Dissolved and Suspended Organic Ingredients and Fatty Acids.
Yes.	Yes.	Yes.	Sulphate of calcium: Yes. Nitrate of calcium: No.	Calcium chloride: No. Magnesium chloride: Yes. At and above 4 atmospheres (53.8 lbs.).	No.	Yes.
a small amount e compounds are ied in natural .	Carbonate of calcium is soluble up to between 2 and 3 German degrees of hardness. Calcium bicarbonate is considerably more soluble up to 65 German degrees of hardness.	Calcium bicarbonate is soluble up to 65 German degrees of hardness. Magnesium bicarbonate is considerably more soluble.	Sulphate of calcium is soluble at: 0° C. 1 part in 415 parts water; 18° C. 1 " " 386 " " 99° C. 1 " " 451 " " At 140° C. it is completely precipitated from the water. Nitrate of calcium is much more soluble.	Very easily dissolved.	1 part in 1.7 parts of water at 0° C.	Usually only a small amount is contained in water.
ible with difficulty, as 1 part of burnt lime (CaO) dissolves ng a long time the solubility of the caustic lime decreases lness.		*a.* Carbonate of soda (soda ash).			*a.* Caustic lime and magnesium sulphate. *b.* " " " iron sulphate. *c.* " " " calcium sulphate. *d.* " " " sodium bisulphate.	Caustic lime, alum, and in carbonic-acid waters with caustic lime alone.
ting alone without precipitants.	*b.* Heating alone without precipitants.	*b* Heating alone without precipitants.		*b.* Heating with soda ash.	*b.* Heating with gypsum water or sulphate of iron.	Chloride of iron, soda ash.
neans of caustic da or caustic me the oxides of on and alumina ill be precipitad as hydroxide iron and aluina. onate of iron mpounds allow e iron to precipate as hydroxide iron on heating.	*a.* $CaH_2(CO_3)_2+2NaOH = CaCO_3+Na_2CO_3+2H_2O$. $CaH_2(CO_3)_2+Ca(OH)_2=2CaCO_3+2H_2O$. *b.* By heating without precipitants: $CaH_2(CO_3)_2=CaCO_3+H_2O+CO_2$.	*a.* $CaH_2(CO_3)_2+Na_2CO_3=CaCO_3+2NaHCO_3$. The bicarbonate of soda transposes $2NaHCO_3=Na_2CO_3+H_2O+CO_2$ $MgH_2(CO_3)_2+Na_2CO_3=MgCO_3+2NaHCO_3$, and as above $2NaHCO_3=Na_2CO_3+H_2O+CO_2$. *b.* $CaH_2(CO_3)_2=CaCO_3+H_2O+CO_2$. $MgH_2(CO_3)_2+2H_2O$ heated under a pressure of 4 atmospheres (58.8 lbs) gives $Mg(OH)_2+2H_2O+2CO_2$.	$CaSO_4+Na_2CO_3=CaCO_3+Na_2SO_4$. $Ca(NO_3)_2+Na_2CO_3=CaCO_3+2NaNO_3$.	*a.* $CaCl_2+Na_2CO_3=CaCO_3+2NaCl$. By heating the transposition takes place more actively than when in a cold condition. *b.* $MgCl_2+Na_2CO_3=MgCO_3+2NaCl$.	*a.* $2NaHCO_3+2Ca(OH)_2+MgSO_4 = 2CaCO_3+Na_2SO_4+Mg(OH)_2+2H_2O$. *b.* $4NaHCO_3+4Ca(OH)_2+2FeSO_4 = 2CaCO_3+2Na_2SO_4+Fe_2(OH)_6+2H_2O$. *c.* $4NaHCO_3+2Ca(OH)_2+2CaSO_4 = 4CaCO_3+2Na_2SO_4+4H_2O$. *d.* $NaHCO_3+Ca(OH)_2+NaHSO_4 = CaCO_3+Na_2SO_4+2H_2O$.	By the introduction of caustic lime and alum a large flaky precipitate will be thrown down which will carry with it the suspended matter. By the introduction of chloride of iron into an alkaline liquid a precipitate of iron hydroxide is created, to which the various particles attach themselves and by their weight hasten the clarification. Fatty acids will be saponified by soda and be converted into insoluble compounds by means of lime
te of soda. ate of soda.	As $CaCO_3$ is very soluble in water very little of the above-mentioned material remains in it.	Regenerated soda ash ready for further transposition with fresh quantities of bicarbonates and the existing carbonic acid.	Sulphate of soda. Nitrate of soda.	Sodium chloride.	Sodium sulphate. Sodium hydroxide.	Sodium stearate. Calcium sulphate (gypsum). Hydrochloric acid, etc.
um hydroxide. droxide. carbonate.	Calcium carbonate.	Calcium carbonate as sludge. Carbonate of magnesia in so far as it is insoluble, and as the solubility is destroyed it exists finally as magnesium hydroxide.	Calcium carbonate.	Calcium carbonate.	Calcium carbonate. Magnesium hydroxide. Ferric hydroxide.	Organic material besides Aluminum hydroxide. Calcium carbonate. Calcium stearate.

igh pressures in the boiler into $Mg(OH)_2$ and CO_2.

1 gram CaO is equivalent to 1.43° NaOH $=1.79$ grams $CaCO_3$ $=1.49$ grams $MgCO_3$ $=.786$ grams CO_2 calculated in terms of calcium (CaO).
1.89° Na_2CO_3 of 100% $=2.57$ " $CaH_2(CO_3)_2=2.28$ " $MgH_2(CO_3)_2$.
2.11° " " 90% $=2.43$ " $CaSO_4$ $=2.14$ " $MgSO_4$.

To face p. 43.

Munich at the order of the Association of Chief Boiler Inspectors.*

4. CONDENSATION OF STEAM AND REUSE OF THE WATER SO OBTAINED.

The utilization of condensed steam as boiler feed-water is of great advantage, as not only is the heat existing in the condensed water gained, but the water is perfectly pure and forms no scale.

Not in every case but frequently in larger establishments, this water softening must be dispensed with, for lack of that water which is necessary for condensation.

5. THE PURIFICATION OF WATER BY SOFTENING.

The settling of the precipitates taking place in the boilers is to be especially avoided in locomotive and particularly in tubular boilers, as it fastens itself to the inaccessible parts of the tubes and especially to the tube-sheets and, by thickening these, leads to tearing of the same and burning of the edges.

The betterment of the water must therefore take place before it enters the boiler. But it is to be noted that neither too much nor too little of the purifying chemicals must be added, or else on the one hand the water, being too alkaline, will foam, or on the other hand, in spite of the previous treatment, scale will form in the boiler.

In the purification of water (that is, the chemical purification before entering the boiler) the action of the precipitants on the scale-forming matter in the water is made plain in column IV, Table B.

In this table are specially set out the precipitants employed by Von Stingl: caustic lime, caustic soda, and soda-ash.

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*Quotation from translation by the writer, of "Die Reinigung des Wassers," by Dr. O. Kröhnke.

The remedies referred to would be called secret boiler compounds in this country.

According to later authorities barium oxide is mentioned as a precipitant, but it is still very costly. One must therefore always recover the first-named material. Also a difficulty is experienced in the filtering of the sulphates on account of the occurrence of extremely fine barium sulphate as precipitate.

These three precipitants (caustic soda, caustic lime, and soda-ash) should remove the chemically bound scale-forming matter in the water as insoluble precipitates.

The remaining suspended material in the water will largely be carried down by the coagulating action of the precipitate itself, or will be removed by natural or artificial filters.

According to Prof. Kalmann (on the basis of Stingl's principles for the purification of water) the lime and magnesia compounds to which the hardness is due will be placed in three groups.

In the first of these groups are included all calcium salts with the exception of bicarbonate of calcium.

These are the salts: $CaSO_4$, $Ca(NO_3)_2$, $CaCl_2$.

All these salts will be precipitated out by soda-ash as follows:

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3;$$
$$Ca(NO_3)_2 + Na_2CO_3 = 2NaNO_3 + CaCO_3;$$
$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl.$$

In the second group Prof. Kalmann includes the bicarbonates of lime and magnesia. These will be precipitated out by caustic soda or caustic lime. In the precipitation by the former, soda-ash is created in the water.

If we add caustic soda to the bicarbonates, the soda-ash in every case is represented by the following equations:

$$CaH_2(CO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O;$$
$$MgH_2(CO_3)_2 + 4NaOH = Mg(OH)_2 + 2Na_2CO_3 + 2H_2O.$$

If, on the contrary, we treat the bicarbonates of lime and magnesia with caustic lime, we precipitate carbonates of lime as well as magnesium hydroxide without the formation of soda-ash:

$$CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O;$$
$$MgH_2(CO_3)_2 + 2Ca(OH) = Mg(OH)_2 + 2CaCO_3 + 2H_2O.$$

We have shown above that by the addition of caustic soda to the bicarbonate of calcium or the bicarbonate of magnesia Na_2CO_3 (soda-ash) is formed in the water.

If besides the bicarbonates of CaO and MgO there are other calcium salts present, namely, $CaSO_4$, $Ca(NO_3)_2$, $CaCl_2$, this soda will now serve to precipitate these also.

Only three cases are conceivable.

Case 1. When the necessary quantity of soda-ash for the precipitation of the first group is smaller than the quantity which can be created in the water by the methods described above.

We must then add a further quantity to precipitate all the calcium.

It follows, therefore, in this case that the softening is made with caustic soda and caustic lime.

As an example if the water contains:

1 molecule $CaSO_4$,
1 “ $CaH_2(CO_3)_2$,
1 “ $MgH_2(CO_3)_2$.

$\Bigg\}$ If we need 1 molecule of soda-ash for precipitation of the gypsum and can get, by adding 6 molecules of NaOH, 3 molecules of soda-ash,

we then have 2 molecules of soda-ash too much, which would make the water too alkaline.

We must therefore take 2 molecules NaOH and 2 molecules $Ca(OH)_2$ in order to purify the water.

Case 2. When the necessary quantity of soda-ash for the precipitation of the first group is just equal to that which is created in the water by the precipitation of the second group with caustic soda.

In this case it follows that the softening is effected by caustic soda alone without caustic lime.

Example.—The water contains:

3 molecules $CaSO_4$,
1 " $CaH_2(CO_3)_2$,
1 " $MgH_2(CO_3)_2$.

If we need 3 molecules of soda-ash for the precipitation of the gypsum and can get, by adding 6 molecules of caustic soda, 3 molecules of soda-ash,

we then have obtained just enough soda-ash to precipitate the gypsum.

We must therefore take 6 molecules causticized soda-ash or 6 molecules NaOH.

The soda-ash is causticized by the addition of the corresponding amount of caustic lime.

CASE 3. If for the precipitation of the calcium not bound by carbonic acid more soda-ash is necessary than will be formed in the water by the combination of the carbonic acid with the caustic soda.

In this case we must add the needed amount of soda-ash to the water as such.

It follows, therefore, that the softening is effected with caustic soda and soda-ash.

Example.—The water contains:

4 molecules $CaSO_4$,
1 " $CaH_2(CO_3)_2$,
1 " $MgH_2(CO_3)_2$.

If we need 4 molecules of soda-ash for the precipitation of the gypsum and can get, by adding 6 molecules of NaOH to the water, 3 molecules of soda-ash,

then we must add 1 molecule soda-ash to the water.

It is well to note that in these three cases the presence at the same time of salts contained in the first and second groups makes the purification somewhat complicated.

On the other hand, again, the precipitation of the magnesia bound to SO_3, NO_3, and Cl is very simple. These salts represent a third group and are precipitated with caustic soda and also with soda-ash in causticized form.

There remains yet one class of waters, which contain, besides lime and magnesia compounds, also bicarbonate of soda. Such water occurs usually in the Hungarian deep wells, more seldom in other places, as, for example, in Lower Austria near Inzersdorf.

If such a water is used in a locomotive-boiler, a violent foaming occurs after a short operation owing to the concentration of the soda solution in the boiler. Also after a longer time the appearance shows that the copper of the fire-box sheets and likewise the stay-bolts are eaten away, while the iron boiler-plates and the rivets do not suffer. The cause of these phenomena lies in the action of the carbonic acid on the copper. The chemical purification of these waters is noted in Table B, column 8, lines IV and V.

CHAPTER V.

DETERMINATION OF THE AMOUNTS OF REAGENTS.

Formula of Prof. Kalmann.

According to Prof. Kalmann it is sufficient for the technical analysis of ordinary water to ascertain the calcium, the bound carbonic acid, and the total hardness determined with soap solution.

For the determination of the latter it is recommended that the water be also analyzed for its strength in magnesia and iron, as the sum of the calcium, magnesia, and iron in terms of their equivalents in calcium must later equal the total hardness.

The bound carbonic acid, the lime, and the magnesia, besides the iron, may be determined according to a simplified procedure.

After the establishment of the contents of foreign matter the water can be improved by chemical additions which, according to Prof. Kalmann, are to be calculated in the following very simple manner.

If we take (*a*) the bound carbonic acid, (*b*) the total lime, and (*c*) the total hardness, and reduce these quantities, according to their composition, to their equivalents in calcium, we may obtain the required quantities to be added of lime, caustic soda, and soda-ash from the following formula:

$$2a-b=m. \qquad (1)$$

$$c-a=n \qquad (2)$$

If m and n are positive, the water contains more carbonates than sulphate. The number m stands then for the quantity of lime required, and n represents the caustic soda. (Case 1.)

If $2a-b=0$, the carbonates are equal to the sulphate contained in the water. We then use no lime, but only add n parts of caustic soda. The caustic soda by mixing with milk of lime creates soda-ash and then precipitates. (Case 2.)

If $2a=b$ is negative, the water contains more sulphate than carbonate and we should add m parts soda-ash solution and $c-a-m$ parts caustic soda. (Case 3.)

The application of the two formulas given above is made clear by the following example.

CASE 1. If the chemical analysis of 100 liters gives 22 grams bound CO_2, in terms of CaO, $a=28$ CaO degrees; 16 grams total lime, $b=16$ CaO degrees; 20 grams magnesia, also in terms of CaO, $=28$ MgO. So the total hardness given by the sum of the CaO and MgO, $c=16^\circ+28^\circ=44^\circ$. We have also

$$2a-b=56-16=40^\circ \text{ CaO},$$

$$c-a=44-28=16^\circ \text{ caustic soda},$$

to be added to the water.

We must therefore add $\frac{40 \text{ gr.}}{100}$ CaO or .4 gram CaO in a soluble form, preferably saturated lime-water. As 1 liter of the most highly saturated lime-water possesses a hardness of 120 CaO degrees and contains 1.2 grams CaO, therefore for 1 liter of water $\frac{.400 \text{ gr.} \times 1000 \text{ c.c.}}{1.2}=333$ c.c. saturated lime-water are necessary.

Taking up the 16° of caustic soda shown. As 16° of caustic soda may be created from 16° of soda-ash and 16° of lime, and one lime degree is 1.89 grams of soda-ash, to yield 16° of caustic soda $16\times1.89=30.24$ grams of 100% soda-ash are required. From the above, 16° of lime are contained in $\frac{.160\times1000}{1.20}=133$ c.c. saturated lime-water; therefore we must add to 1 cubic meter of the water 333+133=466 liters of saturated lime-water of 120° strength, and also .3024 kg. 100% soda-ash in dissolved form.

CASE 2. If the analysis of 100 liters of the water gives 7.9 grams bound CO_2 or reduced to CaO, $a=10$ CaO degrees for CO_2; 20 grams total lime, $b=20$ CaO degrees, and $c=29$ CaO degrees total hardness. Then we have

$$2a-b=0 \text{ CaO and } c-a=19° \text{ caustic soda.}$$

One liter of water should be mixed with 19° of caustic soda. As 19° of caustic soda would be formed from 19° of soda-ash and 19° of caustic lime, and as 1 lime degree=1.89 gr. of 100% soda-ash, therefore for 19° of caustic soda there are required $19\times1.89=35.91$ grams of soda-ash and $\frac{.19\times1000}{1.2}=158$ c.c. of saturated lime-water. Therefore we must add to 1 cubic meter of the water .3591 kg. 100% soda-ash and 158 liters of saturated lime-water of 120° of hardness.

CASE 3. If the analysis of 100 liters of water gives 7.9 grams bound CO_2 reduced to CaO degrees, and $c=40$ CaO degrees of total hardness, then, as

$$2a-b=20-30=-10°,\quad c-a=40-10=30°,$$

the raw water would be mixed with 10° of soda-ash and 30-10=20° of caustic soda. We must compute, therefore, the amount of lime to form 20° of caustic soda with 30° of soda-ash. Hence we must use for 1 liter of water $30\times1.89=56.70$ gr. of 100% soda-ash and $\frac{20\times1000}{1.2}=166$ c.c. lime-water, and add to 1 cubic meter 56.7 gr. 100% soda-ash in dissolved form and 166 liters of saturated lime-water in order to completely purify the raw water.

The soda should be in the form of calcined or ammonia soda, and the lime burnt or slaked, but both should be in dissolved form.

Calculation of the Quantity of the Reagents according to Prof. Kalmann.

If we consider the composition of the water and assume that all the materials are converted to their equivalent molecular weights in calcium, then the amounts to be added may be likewise placed in terms of calcium, namely, the caustic soda, caustic lime, and soda-ash, which are to be added to the water in order to cause the precipitation of the lime as well as the magnesia.

If, for example, the water was of the following composition,

$$\overbrace{z\text{ gr. }CaSO_4}^{\text{Group I.}}+\overbrace{x\text{ gr. }CaH_2(CO_3)_2+y\text{ gr. }MgH_2(CO_3)_2}^{\text{Group II.}}+\overbrace{r\text{ gr. }Mg(NO_3)_2}^{\text{Group III.}}$$

($z=.3$ gram), then there are .3 gram $CaSO_4$ (gypsum) contained in this water. To this gypsum is now to be added as much soda-ash, according to its equivalent molecular weight, so that the precipitation will be a complete one.

This is the case when, according to the equivalent molecular weights of the material,

$$.3:z=136:106\,*$$

$$z=\frac{106\times .3}{136}=.234 \text{ gram of soda-ash will be required.}$$

In exactly the same way we will calculate all the other substances in the water to calcium according to their equivalent molecular weights, and we will obtain for their values z, x, y, and r, referred to calcium, in equivalent numbers which we may use directly in the calculations.

If we desire to calculate, according to Kalmann, how to soften a water of the following composition, in which the carbonate compounds exceed the gypsum (Case 1),

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* 136 = molecular weight of $CaSO_4$;
106 = " " " Na_2CO_3

$$\underbrace{\underbrace{\overbrace{z\text{ gr. CaSO}_4}^{\text{Group I.}} + \overset{\text{Group II.}}{x\text{ gr. CaH}_2}}_{b\text{ (total hardness)}}\underbrace{(\text{CO}_3)_2 + y\text{ gr. MgH}_2(\text{CO}_3)_2}_{a\text{ (carbonic acid)}}}_{c\text{ (total hardness)}} + \overbrace{r\text{ gr. MgSO}_4}^{\text{Group III.}}$$

precipitated by caustic soda

we will use for the precipitation of the compounds $z\text{CaSO}_4 + r\text{MgSO}_4$ (by which we show the simplicity of all the other salts belonging to this group: $\text{Ca(NO}_3)_2$, CaCl_2, besides $\text{Mg(NO}_3)_2$, MgCl_2, etc.):

$z+r$ parts of soda-ash, then the CaSO_4 will be precipitated by means of soda-ash and MgSO_4 by means of causticized soda-ash (caustic soda).

But we may create from the water, in consequence of the reaction of the caustic soda added to the water, with the bicarbonate salts contained in it, $x+2y$ of soda-ash.*

We do not need all of this $x+2y$ of soda-ash, as we only have need of z parts soda-ash for the amount of gypsum present.

We may not add the difference, that is $x+2y-z$, as caustic soda, but must add it as Ca(OH)_2 to the water, because otherwise an excess of soda-ash would occur in the water.

The difference, $x+2y-z$, shows the amount of lime necessary.

As now x, y, z, and r, which refer to soda-ash, are the numbers corresponding to the amounts of active substances in the water, there is

$x+y=a$, the amount of soda-ash corresponding to the carbonic acid in the water, which is composed of the amount (x) corresponding to the calcium carbonate, increased by the quantity (y) corresponding to the magnesium carbonate. Moreover, there is

$x+z=b$, the amount of soda-ash corresponding to the total calcium, which is composed of the quantity (x) corresponding to the calcium carbonate, increased by the quantity corresponding to the rest of the lime salts, which we have designated by z. Finally, there is

---

* $2y$, because 1 molecule of magnesium bicarbonate requires 2 molecules of caustic soda for uniting 2 molecules of carbonic acid.

$x+y+z+r=c$, the amount of soda-ash corresponding to the total, hardness of the water, which is composed of x, y, and z and that amount which corresponds to the magnesia not united with carbonic acid, and which we have designated by r; z, on the contrary, shows us the amount of soda-ash in caustic form, which will be changed back into ordinary soda-ash by the bicarbonates and which serves to precipitate the gypsum.

r is the amount of soda-ash remaining in caustic form which is necessary for the precipitation of the magnesium sulphate selected as a substitute for Group III.

Therefore for the case when more carbonates than gypsum are present,

$x+2y>z$, there is to be taken
$x+2y-z$ parts as calcium and $z+r$ parts of soda in caustic form.

But as $x+y=a$, $z+x=b$, and $x+y+z+r=c$, then $x+2y-z=2a-b$ and $z+r=c-a$.

For softening a water in which there are, according to Case 1, more carbonates than gypsum, there is to be taken

$2a-b$ in lime (calcium),
$c-a$ in soda in caustic form.

If we now consider (Case 2) where equal amounts of gypsum and carbonates are present, we need again for softening $z+r$ of soda, one part of which may be in the natural condition (sodium sesquicarbonate) and the other as caustic soda.

As previously mentioned, $(x+2y)$ parts of caustic soda would create with the water $(x+2y)$ parts of soda-ash.

If now $x+2y=z$, the caustic soda added to the water to precipitate the gypsum as represented by Group I, it will combine with the carbonic acid compounds and will form enough soda-ash in the water, so that the water needs neither lime nor more soda-ash.

For precipitating the magnesium sulphates as represented by Group III (r) parts of caustic soda are required, so that $z+r$ or $z+2y+r$ caustic soda is necessary for the precipitation of Groups I and III.

But now $x+y=a$, also
$$\begin{aligned} 2x+2y&=2a,\\ z+x\ &=b,\\ x+2y-z&=2a-b; \end{aligned}$$

but $x+2y-z$ is from above equal to zero, therefore $2a-b=0$, and as $x+2y+r=z+r$, $z+r=c-a$.

If $2a-b=0$, we still need in this case $c-a$ parts of causticized soda-ash only (caustic soda).

Case 3. Here more gypsum is present than carbonates:

$$x+y=a,$$
$$z+x=b,$$
$$x+y+z+r=c.$$

We require here again $z+r$ soda in the caustic form of natural soda (sodium sesquicarbonate).

If $x+2y$ of caustic soda is added to the water $x+2y$ soda-ash is produced.

This is too little for Case 3, as more sulphates than carbonates are present.

We therefore need in addition to the $x+2y$ parts of soda-ash by weight n parts of natural soda (sodium sesquicarbonate) or $x+2y+n$.

This quantity completely precipitates the gypsum.

Then $x+2y+n=z$.

But for the total precipitation of all salts $x+2y+n+r$ of natural soda (sodium sesquicarbonate), as well as in caustic form, is required.

As $z+r$ soda in one form or the other is needed in all cases,

$$z+r=x+2y+n+r, \quad \text{and} \quad z+r=c-a;$$

therefore

$$c-a=x+2y+n+r$$

or

$$c-a-n=x+2y+r.$$

But as $$x+y=a,$$

$$\left.\begin{aligned}2x+2y&=2a\\ x+z\quad&=1b\end{aligned}\right\}\text{and from this } 2a-b=x+2y-z.$$

In connection with

$$c-a-n=x+2y+r$$

we have

$$c-3a-n+b=r+z,$$

and because $r+z=c-a$ we have finally

$$-2a-n+b=0 \quad\text{or}\quad -(2a-b)=+n$$

in sodium sesquicarbonate.

Now as on the whole no more soda-ash may be used than $z+r$ parts by weight and $z+r$ parts by weight $=c-a$, and further as n parts by weight natural soda (sodium sesquicarbonate) is to be used, there remains to be added in causticized soda (caustic soda) $=c-a-n$ parts.

Test of Kalmann's Formula.

If we now consider an example for testing these formulas of Kalmann. It is permitted me to follow in this study the same method of which I had written before having known of Kalmann's formulas for calculating the additions, because it will show the deliberations necessary to a better understanding and the advantage of his formulas.

I have chosen a water which I have purified with good results.

This water was of especial interest because it contained so much $MgH_2(CO_3)_2$, as the following analysis brings out. The water contained:

24.0° bound carbonic acid in cold water (calculated as CaO)
7.5° " " " " boiled water
16.0° permanent hardness (calculated as CaO)
29.0° total " " " "
10.0° calcium " " "
21.0° magnesium oxide " " "
7.0° sulphuric acid " " "

From the results of this analysis I evolved the composition of the water in two ways:

A. 3° $CaH_2(CO_3)_2$ + 21° $MgH_2(CO_3)_2$ + 7° $CaSO_4$.
B. 10° $CaH_2(CO_3)_2$ + 14° $MgH_2(CO_3)_2$ + 7° $MgSO_4$.

Both compositions were possible; the latter was the most likely because the water after boiling showed by titration with $^2/_{10}$ normal hydrochloric acid a strength of 7.5° CO_2 (calculated as CaO), therefore a proportionally large soluble quantity of $MgCO_3$ must be present and therefore gypsum could hardly be present in it.*

While this water might be composed according to A or B, a preheating of the water of the first composition in open vessels could not prevent scale formation in the boilers, because too much $MgCO_3$ was contained in the water and this remains soluble for the most part; the second also could not be used without frequent blowing down and washing out of the boilers fed with this water on account of the great quantity of scale-forming matter.

If a precipitation in the boiler was desired, it is not to be recommended, because the quantity precipitated in the boiler must be very large. Therefore a purification of the water before it enters the boilers is the only plan.

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* $MgCO_3$ in the water and gypsum transpose themselves.

If I were in position to be able to say how much carbonate of magnesia or how much gypsum or sulphate of magnesia was contained as combinations in the water, every uncertainty would vanish and the proper composition of the water could be described at once and the softening of the water would be ascertained.

But unfortunately the determination of the separate compounds as such is not generally possible. I therefore made two limited investigations in order to be able to select the better softening process from the composition of the water. As the better results of softening were given from composition B, I will only carry out the softening for this composition.

Water B contained

$$10° \mathrm{CaH_2(CO_3)_2} + 14° \mathrm{MgH_2(CO_3)_2} + 7° \mathrm{MgSO_4};$$

therefore the following additions are to be added in order to precipitate the lime and magnesia:

Water.	Addition.	Final Results	
		in the Solution.	in the Precipitate.
10° $CaH_2(CO_3)_2$	10° $Ca(OH)_2$	10° H_2O	20° $CaCO_3$
14° $MgH_2(CO_3)_2$	28° $Ca(OH)_2$	28° H_2O	14° $Mg(OH)_2$ + 28° $CaCO_3$
7° $MgSO_4$	7° NaOH	7° Na_2SO_4	7° $Mg(OH)_2$

Therefore the purification of the water is complete by the addition of

7° NaOH . . . . (1)
38° $Ca(OH)_2$.

As the number of calcium degrees are 7 and 38, and 7 calcium degrees indicate a calcium content of 7 grams in 100 liters of the water; as, further, according to the molecular weights, 56 and 106 of calcium and soda-ash 7 grams CaO : x grams 100% soda $=56:106$; so for 100 liters of water there is required

$$x=\frac{7\times106}{56}=13 \text{ grams } 100\% \text{ soda-ash,}$$

and in consequence of the hardness 38° $Ca(OH)_2=38$ grams CaO.

Now, as the lime-water for use in the softening must be saturated, and as such has a strength of 130°, to each 100 liters of the raw water must be added 13 grams of 100% soda-ash and $\frac{38}{1.3}=29.21$ liters of saturated lime-water.

We arrive at exactly the same results if we take first the caustic soda as united with the bicarbonate of lime, whereby the 7° of caustic soda and 7° calcium bicarbonate are changed into simple calcium carbonate, by which 7° of soda-ash are produced and a remainder of 3° of calcium bicarbonate remains in the water.

This 7° of soda-ash must now be converted into caustic soda by the further addition of 7° of calcium, which caustic soda acts to break up the bicarbonates of lime and magnesia still present, forming soda-ash, which will be converted by the addition of fresh lime again into caustic soda, until it finally completely transposes itself with the magnesium sulphate remaining finally in the water.

The caustic soda therefore plays a transmitting rôle in the water.

We will now calculate the additions according to Professor Kalmann, and maintain as in the previous case the composition

$$\underbrace{\underbrace{(z=)0^\circ\,\mathrm{CaSO_4}+}_{b}\underbrace{(x=)10^\circ\,\mathrm{CaH_2(CO_3)_2}+}_{a}\underbrace{(y=)14^\circ\,\mathrm{MgH_2(CO_3)_2}+(r=)7^\circ\,\mathrm{MgSO_4}}_{r}}_{c}$$

$$\begin{array}{ll} a=24 & \\ b=10 & \left.\begin{array}{r} z+r=c\;-a=\;7^\circ \\ x+2y-z=2a-b=38^\circ \end{array}\right\} \quad . \quad . \quad . \quad . \qquad (2) \\ c=31 & \end{array}$$

$2a-b>0$, giving us Case 1.

According to Professor Kalmann's formula a result is found which agrees exactly with the amounts previously obtained and which in a similar manner requires that

$$\text{100 liters of raw water be treated with} \left\{ \begin{array}{l} \text{13 grams 100\% soda-ash.} \\ \text{29.21 liters saturated lime-water.} \end{array} \right.$$

We see, therefore, we may place full reliance in Professor Kalmann's formulas.

This is also shown in another way on pages 49 and 50.

In Case 3 (see pages 46, 48, and 55) the difference $2a-b$ appears negative. This difference indicates when positive a quantity of CaO to be added.

The negative mark indicates therefore that CaO should be taken away. This occurs chemically if we place opposite his CaO an equivalent quantity of soda-ash, by which the lime is precipitated as $CaCO_3$ and caustic soda is obtained.

This caustic soda must then be diminished, which is accomplished by $c-a$ quantity of caustic soda.

A similar deductive process leads us to the addition of sulphate of iron to waters with a content of bicarbonate of soda (see page 66).

Pfeifer's Formula and Comparison of Results by Kalmann's and Pfeifer's Formulas.

On the basis of Stingl's scientific analysis, Pfeifer has worked out a very simple formula by which the addition of lime and soda may be calculated.

1. For the purification of water the necessary addition of lime may be calculated by the following equation:

$$\mathrm{CaO} = 10\ H_t + 1.4\ \mathrm{MgO}.$$

In these formulas we denote

$$\mathrm{CaO} \text{ in } \frac{\text{Milligrams per liter}}{\text{Grams per cubic meter}}.$$

H_t = temporary hardness in German degrees.
MgO = magnesia in milligrams per liter.

2. The soda-ash necessary for the purification of water will be calculated by the following equation:

$$Na_2CO_3 = 18.9\ H_p,$$

where Na_2CO_3 = the carbonate of soda in milligrams per liter;
H_p = the permanent hardness in German degrees.

If we calculate according to Pfeifer and would determine the distribution of the three liquids as in the example previously given, then we have only to express the soda quantities in lime degrees.

According to J. Pfeifer only lime will be employed for the purification of a water containing soda. The formula No. 2 applies to this case as well.

By the Stingl method an equivalent quantity of Epsom salts will be replaced by the caustic soda generated from lime and soda.

The soda in the water can be removed by gypsum solution alone or lime and iron sulphate, or by caustic lime and sodium bisulphate.

The formulas of Kalmann and Pfeifer give exactly the same result. Both formulas are based on the theoretical analysis made by Prof. von Stingl, and the only difference between the two formulas is that Prof. Kalmann calculates the chief compounds in terms of soda and places the figures thus obtained in his algebraic formulas, while Pfeifer in his formulas inserts the value of the calcium, magnesia, permanent and temporary hardness in terms of calcium degrees of hardness. By assigning the proper values to the latter Pfeifer's formulas give the results in milligrams.

In the following demonstrations the material to be added for purifying water of the composition given below is calculated by both the Kalmann and the Pfeifer method, and the quantities of the different compounds are calculated in terms of lime, as described by the author in the Journal of the

Progress of Railways, issues I, II, and III of the Volume for 1903.* The water contains

$$2° \ CaH_2(CO_8)_3 + 3° \ MgH_2(CO_3)_2 + 5° \ CaSO_4 + 4° \ MgCl_2.$$

The quantity of bound carbonic acid is $2° + 3° = 5° = a$;
" " " total lime is $2° + 5° = 7° = b$;
" total hardness is $2° + 3° + 5° + 4° = 14° = c$.

Then, according to Kalmann,†

$$2a - b = 10° - 7° = 3° \ CaO;$$
$$c - a = 14° - 5° = 9° \ NaOH;$$

and as 1 molecule of NaOH is created from 1 molecule of CaO and 1 molecule Na_2CO_3, there must be added as a precipitant to the water

$$9° NaOH + 3° CaO = 9° Na_2Co_3 + 9° CaO + 3° CaO = 9° Na_2Co_3 + 12° CaO$$

or for 1 liter of water 120 mg. CaO and $106/56 \times 9° = 1.89 \times 9° = 17.0$ cg. or 170 mg. soda-ash.

According to Pfeifer ‡ we have

$$CaO \text{ mg.} = 10 \ H_t° + 1.4 \ MgO \text{ (mg.)},$$
$$Na_2CO_3 \text{ mg.} = 18.9 \ H_p°.$$

In these formulas

H_t is the temporary hardness, or $2° + 3° = 5°$;
H_p " " permanent " " $5° + 4° = 9°$.

1 German degree of hardness = 10 mg. CaO in 1 liter of water.

The derivation of Pfeifer's formulas results from the substitution of

1 molecule CaO for each bicarbonate compound;
1 " CaO " " magnesia compound;
1 " Na_2CO_3 " " molecule of permanent hardness.

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* On page 57, column 2, lines 14 to 18 of these issues the same may be seen: 10% soda (made caustic).

† Kalmann, Aid to Water Preparation according to Berenger Stingl. Communication from the Museum of Technology, Vienna, 1890.

‡ Pfeifer, Budapest. Critical Studies on the Investigation and Purification of Boiler Feed-water. Zeitschr. angew. Chemie, 1902, vol. 15, page 193.

Therefore

$$\begin{array}{lllll}
2^\circ CaH_2(CO_3) & +3^\circ MgH_2(CO_3)_2 & +5^\circ CaSO_4 & +4^\circ MgCl_2 & \\
2^\circ CaO & +3^\circ CaO & +5^\circ Na_2CO_3 & +4^\circ Na_2CO_3 & =12^\circ CaO+ \\
 & +3^\circ CaO & & +4^\circ CaO & 9^\circ Na_2CO_3 \\
\hline
2^\circ CaO & +6^\circ CaO & +5^\circ Na_2CO_3 & +4^\circ Na_2CO_3 & \\
 & & & +4^\circ CaO &
\end{array}$$

If the quantities of the materials found as above in Pfeifer's formulas are calculated in milligrams, there results

$$\begin{array}{ll}
CaO \text{ mg.}=10\times 5^\circ+1.4\times 7^\circ\times \tfrac{40}{56}=50 \text{ mg.}+70 \text{ mg.} & =120 \text{ mg.} \\
Na_2CO_3 \text{ mg.}=18.9\times H_p=18.9\times 9^\circ & =170 \text{ mg.}
\end{array}$$

The results are therefore exactly alike. In the case where, in addition to the bicarbonates of lime and magnesia, the water contains also the monocarbonate of the latter material, an accurate analysis to check the softening is necessary, as neither Kalmann's nor Pfeifer's formulas take into consideration these special cases.

Treatment of Alkaline Waters.

If a water on heating has an alkaline character and if the investigation and calculation according to Kalmann shows that the total hardness is less than the alkalinity, it indicates that this water belongs to Class 4.

Let us consider as a special example one such water, which descends from certain strata of the Vienna basin.

According to Dr. Schierholz the water contains in 1 liter

		Calculated to CaO:
Iron oxide and alumina	3.3 mgr.	
Lime (CaO)	29.0 "	2.9°
Magnesia (MgO)	21.5 "	3.01°
Potassium and sodium (Na_2O)	185.0 "	16.70°
Silica (SiO_2)	9.0 "	5.5°
Chlorine (Cl)	8.9 "	1.13°
Sulphuric anhydride (SO_3)	84.0 "	5.88°

Nitrous oxide (N_2O_5)	0.0 mgr.	0.0°
Carbonic acid (CO_2)	370.0 "	47.0° free 23.5° bound
Organic matter	56.0 "	
Suspended matter	0.0 "	

Total hardness	5.901°
Permanent hardness	5.37°

This water, taken from a well 45 meters deep, is characterized by its high content of sodium bicarbonate and is therefore extremely alkaline.

If used in a locomotive, it acquires a strong alkaline character through the soda-ash formed by the driving off of the carbonic acid.

Frequent washing out of the boiler is necessary or else a violent foaming occurs.

But its most harmful property is that it violently corrodes the copper plates, stay-bolts, fire-box, and the metal of the injector, while the iron tubes and iron boiler-plates do not suffer. Copper under certain conditions will be corroded by the acids in the air, but the coating is an insoluble carbonate of copper oxide, while in this instance, in which the copper is eaten away, it appears quite bright and the copper has gone into solution.

Such a solution according to Dr. Schierholz may be caused by the presence of organic substance, carbonic alkalies, and acids of the air.

In this instance the cause of the destruction of the copper is therefore the united action of these materials, whose action is promoted by the concentration of the waters in the boiler and the heat.

Prof. Dr. Oser made further experiments with the same water in the following manner: Metallic copper was treated first with raw water and another time with a slightly alkaline softened water at 160°–200° C. for twelve hours in a closed glass tube under high pressure.

In the first case the copper was attacked much more strongly than in the second case.

It is evident, therefore, that as a matter of fact with higher pressure and with higher temperature the solubility of copper in the raw water is increased.

We may now note as follows:

That the water derived from a bored well 45 meters deep will not usually change in its composition, and the analysis of Dr. Schierholz may be considered in its principal characteristic the true one. A confirmation of this assumption is drawn from the circumstance that, according to an analysis made later by the author, the lime, magnesia, and carbonic acid agreed nearly with the Schierholz analysis.

That soda in every condition strongly attacks copper is a known phenomenon. One need only to mention that the fittings of boilers, to the water of which an excess of soda has been added in order to prevent the formation of scale, become green and by and by through the formation of copper salts suffer a loss of material.

As a remedy for the bad effect mentioned above it is recommended either to frequently blow down the boiler or weaken the alkalinity of the water by the addition of iron sulphate.

From investigations completed it is known that the reaction from the addition of iron sulphate to raw water in a cold condition is very slow, so that therefore a practical use of this reaction in this manner is not feasible.

On the other hand, a heavy precipitate settles quickly, if we add sulphate of iron in hot water. But this method of neutralizing the water is not feasible because a great quantity of precipitate would form in the tender and in the boiler, so that a very frequent washing out would be necessary. It would also cause priming in the locomotive and clogging of the injector. But much worse than this is the fact that, through the formation of a precipitate consisting of precipitated iron oxyhydrate in the boiler and tender, the iron of the boilers is strongly corroded by this precipitate and its combined action with acids. By the above not only would the copper be destroyed, but the iron as well.

It is recommended to use iron sulphate for the neutralization of any soda formed together with a small addition of lime for the separation of the bicarbonate of lime and magnesia in the raw water and when the water is to be filtered.

For 1 cubic meter of the raw water an addition of about 340 grams crystallized sulphate of iron and 200–300 grams calcined 90% calcium oxide is recommended. This method of treatment is not complete, as the calcium, which causes a quick separation of the precipitate, gives in many cases too small a precipitate. This action will take place in the same manner in a cold condition as in a hot condition. If the precipitation occurs in the boiler, the precipitate formed by carbonate of lime consists largely of iron oxyhydrate, which on settling will increase by its action on the boiler-plates.

For instance, an analysis of the boiler-water and the precipitate in the boiler taken after three to four days' operation, made by the chemical laboratory of No. 3 Trunnerstreet, Vienna, shows that the water contains .415 grams CO_2 per liter but neither iron nor copper, while in the precipitate was

44.72 gr. copper (CuO) per liter,
33.20 " iron (Fe_2O_3) " "

The copper was in the form of carbonate of copper; the iron was contained in the slime as iron oxyhydrate.

In order to learn whether this amount increases proportionally or increases progressively with the concentration of the soda solution it would be necessary to make an analysis of the boiler-water and boiler-mud after each one, two, and three days' run of the locomotive.

We could see from this whether a more frequent washing out would bring the consumption of copper to a minimum, so that all installations might avoid this loss.

How often the performance of this operation would be necessary would have to be determined by experience.

It has been proved by the author from the previous experiments and his own previously described calculations of water analyses that the preceding water may be so treated (purified) by means of a proportioned quantity of lime and iron sulphate, that the amount of precipitate settling in the boiler would be hardly worth mentioning.

The process is the following: The bicarbonate of soda will react with a corresponding quantity of caustic lime to form caustic soda and simple carbonate of lime, the latter being precipitated.

The caustic soda on the contrary remains in solution and may be taken up by an addition of iron sulphate, whereby sodium sulphate and iron oxyhydrate are formed, the latter being thrown down as a precipitate.

The bicarbonate of lime will be completely precipitated as carbonate of lime by the addition of caustic lime.

The bicarbonate of magnesia will be changed, so far as is possible by the cold process, into simple carbonate of lime and magnesium hydrate.

By these processes a very good and quick clarification may be obtained. We may calculate the treatment for the raw water according to Kalmann:

$$2a-b=+44.1^\circ \quad \text{CaO};$$

$$c-a=-17.56^\circ \text{ caustic soda};$$

and in order to carry off this caustic soda we must use +17.56° iron sulphate.

According to the extent of the hardness we use for 1 cu. meter 441 grams CaO, and according to page 20, $17.56^\circ \times 4.96 = 87.2$ grams iron sulphate.

But if there remains in the treated water such a quantity of sulphate of iron and caustic soda as would attack the iron of the boilers, a special treatment must be used.

For such cases the following questions are now entered into:

1. Question: Should we recommend treatment consisting

of filling the locomotive boiler with lime-water after each washing out?

To this we must emphatically answer "No."

By filling with lime-water and the heating of the lime-water a great quantity of lime precipitates. According to A. Lamy

At 10° C.......... .1384% lime is soluble in water.
" 100° C........ .0584 " " " " "

It will therefore make all the water in the boiler being fired turbid, unless it was still fed with raw water. But the instant that the boiler is fed and the raw water containing carbonic acid comes in contact with the lime-water in the boiler, a still further turbidity and a consequent precipitation takes place,

Moreover at the same time as much caustic soda is formed as there is lime contained in the boiler. Owing to the existing turbidity and the caustic soda formed (which causes an increasing alkalinity), a strong priming would take place. Besides, it is to be feared that the iron would be attacked by the constantly increasing caustic soda arising from the concentration.

2. Should the copper fire-box be replaced by steel and the copper stay-bolts be wrought iron?

From the foregoing, the replacing of the copper stay-bolts by iron can be recommended unreservedly, as with the use of iron stay-bolts and water pure or containing little or no scale iron stay-bolts are uninjured.

On the contrary the author would advise against the exchange of the copper fire-box for steel on the grounds that the locomotive coke usually burnt will generate a high local temperature. It is to be feared that this would result in a short time in rents in the plates of the fire-box. Besides this, tears in the plates of the fire-box would be caused by the other burning materials, and would limit the use of the same to one year, presuming that the under wall would be dressed with fire-brick (Chamotte).

But besides this, even if the steel fire-box lasts a longer time, the foaming of the locomotive would still exist and the injector would have to be changed frequently, or else it must be taken to the repair-shop frequently, as the water would still contain soda.

3. The best way out would be to see if a better water could be found by an artesian well passed through the strata.

4. An improvement of the situation would be under certain conditions to aim at placing the water stations for the locomotives with regard to the time, so that in service they could pass this station with a better water on hand.

If now it is impossible to arrange according to suggestions 2, 3, and 4, there remains nothing else than to prepare the water by chemical means, so that it loses its soda content, and simultaneously its content of lime and magnesia no longer permits its previous foaming, and no longer corrodes the injector, which may be done in the following manner.

5. We may first purify the water by additions of lime-water and sulphate of iron before entrance into the boiler. But these additions of lime-water and sulphate of iron must be in the proper proportions all the time, and therefore a water-purifying plant must be established. This must consist of a vessel for preparing the sulphate of iron solution and regulators for the dose and for the proper mixture of these liquids with the raw water in a mixing-reservoir, a filter and two small pure-water reservoirs to draw from.

But before such an installation is gone into, a course of treatment must be predetermined by which to fix what alkalinity, what hardness, how much sulphate of iron, and how much caustic soda the prepared water may contain and whether the water so prepared contains properties which will corrode iron.

An improvement of water by the addition of a corresponding quantity of sulphuric acid would only be recommended when the free carbonic acid is driven off (as the latter would lead to corrosion) and it may be removed either by heating or by passing air through the water.

Heating of such a great quantity of water is not practicable; the passage of air through the water by rising currents of air is possible, but is not yet used in many places.

The addition of lime-water and magnesium sulphate is more frequent as devised by Prof. Stingl (see page 43, Table B), and the two operations will be described hereafter, by which first caustic soda and then sulphate of soda and magnesium hydroxide are formed.

Finally, the bicarbonate of soda is converted by lime-water into caustic soda, and after clarification the caustic soda according to Prof. Kalmann is neutralized by an addition of sodium bisulphate.

The fact that with waters under Case 2, whose content of sulphate of lime is equal to the carbonate and which may be entirely purified with caustic soda, and that by a purification with caustic soda especially good results of purification are achieved (great softness, small alkalinity), awoke in the author the thought that water with a preponderating content of carbonates, whose purification by means of the lime-water and soda-ash method gives an imperfect result, might be given the properties of Case 2 by the addition of sulphuric acid to the water before purification and then be purified with caustic soda.

Chief Chemist Grittner of the Imperial State Railway, however, found this method would only accomplish its object if the carbonic acid could be driven off. The caustic soda combined itself with the carbonic acid remaining in the water, and on this account the water remained hard. A satisfactory result was only achieved by driving off the carbonic acid by a current of air or by heating.

CHAPTER VI.

TESTING THE SOFTENING.

AFTER the investigation of the water as described and the calculation of the additions have been made according to Kalmann's method, the correctness of the ascertained result will be tested in greater quantity by means of a softening process.

For this purpose 100 liters of raw water will be placed in a cleaned petroleum barrel for heating; lime-water will be made in a second similar barrel, in which 1 kg. lime is dissolved, the barrel filled with water, and contents well stirred, then allowed to clear in quiet. The clear liquid is the lime-water, possessing a hardness of from 120° to 125°.

The lime-water must have its strength investigated: 56 c.c. of it is measured out, colored with indicator and treated with a measured quantity of $^2/_{10}$ normal hydrochloric acid from a burette graduated in $^1/_{10}$ c.c.

The number of $^1/_{10}$ c.c. of the $^2/_{10}$ normal HCl, required for the color change gives the degrees of hardness. The $^2/_{10}$ normal HCl must contain as much HCl as would correspond to 560 degrees of hardness.

As 1 liter of $^2/_{10}$ normal HCl contains 7.3 grams HCl, and 36.5 grams HCl corresponds to 28 grams CaO, 7.3 grams HCl corresponds to $\frac{7.3\times 28}{36.5}=5.6$ grams CaO in 1 liter.

According to the definition of hardness, one degree of hardness is the containing of 1 part by weight in 100,000 parts by weight of water, or .01 gr. in 1000 gr. = 1 liter of water;

but as 5.6 gr. CaO is 560 times .01 gr. CaO, the strength of $^2/_{10}$ normal HCl is 560 lime degrees.

If, now, for example, it requires 130 $^1/_{10}$ c.c. of $^2/_{10}$ normal HCl to neutralize 56 c.c. lime-water, the strength of the latter will be $130/10 \times 560° = 56x$, $x = 130°$. The lime-water has, if 56 c.c. of the same is taken, just as many degrees of hardness as the number of $^1/_{10}$ c.c. $^2/_{10}$ normal HCl used for neutralization.

In a similar manner prepare and investigate the strength of the caustic soda solution.

Take 100 liters of raw water in a third barrel and dissolve about 4 kg. of soda-ash in a smaller quantity of warm water; add this to the 100 liters of raw water, then make it caustic by dissolving in it 4 kg. of burnt lime, and soda solution is produced. After the necessary quietness and settling the strength of the caustic soda in the liquid may be determined.

As the caustic soda solution is very strong and would require too much $^2/_{10}$ normal HCl to neutralize any considerable quantity, we cautiously draw out 10 c.c. of the caustic soda liquid into a measuring-glass with the help of a pipette, place in a flask 30 c.c. $^2/_{10}$ normal HCl, color this with the mixed indicator and allow the caustic soda to drop from the measuring-flask into the $^2/_{10}$ normal HCl.

This shows the strength (x) of the solution in caustic soda in lime degrees, if m represents the number of cubic centimeters of caustic soda used, by the equation $30:560::m:x$.

If, for example, we have produced in the above manner caustic soda of 1600° (by the solution of 4000 grams of 100% soda-ash in 100 liters of water, and if the caustic soda liquid had no other losses, it would have a strength of $4000:x::53:28$, $x = 2113°$ $Na_2CO_3 = 1600°$ NaOH, and if it were calculated that for softening the water 7° NaOH and 38° $Ca(OH)_2$ was necessary, then we must add to 100 liters of raw water $100 \times 7° = x \times 1600°$, $x = .437$ liters of this caustic soda liquid and $100 \times 38° = y \times 130°$, $y = 29.2$ liters of lime-water, in order to soften the 100 liters of raw water.

The error which will be made on account of there being lime-water as well as caustic soda liquid in the solution and that therefore the 1600° does not all consist of caustic soda is not important, because the lime in the presence of so strong a solution of caustic soda is much less soluble; but if at all events the quantity of lime-water mentioned contained in the soda solution is less than 75°, the 1600° mentioned must be increased at the most about 75°.

From the result of this softening test it can now be told what small changes are necessary in order to carry out the softening on a large scale.

If a purifying plant is installed, the supervision of the managing engineer is necessary from time to time to examine the purity and uniformity of the purified water, the lime-water, and the soda solution, as well as the uniformity of the raw water.

The following simple means suffice for the pump operator to make tests from time to time:

1. Test by allowing a drop of purified water to drop on litmus paper.

If the water possesses alkaline characteristics, a plain brown color occurs.

2. Test for alkaline properties and the bound carbonic acid by treating a sample of water colored with mixed indicators and titrating by means of $^2/_{10}$ normal HCl (each $^1/_{10}$ c.c. of acid used = 1°).

3. Test for total hardness by titrating with soap solution. The pure water must first be neutralized.

4. Test for a surplus of the added chemicals or presence of untreated carbonate of magnesia, by heating a small quantity of purified water treated with the indicator.

In the absence of such an excess, or in the presence of dissolved carbonate of magnesia, the liquid will turn yellow on heating; in the other case it remains colored red or orange yellow.

5. Test for the result of the apparent purification in three

drinking glasses. Place purified water in each of them and then treat the row with testing chemicals as in the following table:

1	2	3	4
Glass I.	Muriate of ammonia Oxalate " " Ammonia	Notice any existing turbidness or formation of precipitate.	Unprecipitated lime or excess of lime-water.
Glass II.	Soda-ash solution		Unprecipitated calcium sulphate or excess of lime-water.
Glass III.	Lime-water (the glass must be stoppered in order to keep out air).		Unprecipitated carbonate of lime or magnesia salts or excess of soda.

The investigation of water by mixing liquid additions with purified water or by pouring together purified and unpurified water is to determine from the resulting turbidness whether there is too great an alkalinity or an incomplete purification, and to determine the changes of the amounts of the added chemicals required. The use of gypsum-water will also be necessary for the determination of an excess of soda-ash, or the use of Epsom-salt solution for the determination of an excess of caustic soda, in very rare cases, as only a minute excess of these substances may exist in the water.

By observing the behavior of the purified water after the mixture of the treated water with these liquid additions, we will soon perceive the necessary changes to be made in the quantities added, and notice from this a satisfactory change in the water purification, or perceive the possibility of improving the apparatus.

6. Investigation of the lime-water. The lime-water must be clean and pure and have a lime strength of 120°.

56 c.c. lime-water is colored red with 2 or 3 drops of indicator, a mixture of methyl orange and phenolphthalein.

Now drop in $^2/_{10}$ normal HCl from a burette graduated in $^1/_{10}$ c.c. until the color changes from red to yellow.

The number of $^1/_{10}$ c.c. of $^2/_{10}$ normal HCl used indicates the degree of alkalinity.

7. Investigation of the soda solution. The soda solution should have its degree of saturation prescribed in degrees of lime.

30 c.c. of $\frac{2n}{10}$ HCl will be colored red with two drops of indicator, and soda-ash solution dropped in from a burette graduated in $^1/_{10}$ c.c. until the color changes from red to yellow.

The following gives the result when the color change occurs from this addition: *

5.6	c.c.	soda	solution.	The soda-ash	solution	contains	500°
2.8	"	"	"	"	"	"	1000°
1.86	"	"	"	"	"	"	1500°
.93	"	"	"	"	"	"	3000°

If more soda solution is used for the change of color, this is too weak, then more soda is to be placed on the sieve.

8. For investigating the German degrees of hardness 25 c.c. of the pure water to be investigated is first made neutral, and freed of free carbonic acid by blowing in air according to Prof. Blacher (of Riga), then diluted with 75 c.c. of chemically pure water in a shaking-flask. Now treat with soap solution a drop at a time from a burette graduated in $^1/_{10}$ c.c. and shake until a foam forms which will remain at least for 5 minutes, and which appears to stand longer after being violently shaken again.

The number of cubic centimeters of soap solution used according to Faist and Knauss gives the German degrees of hardness as follows:

---

* On the basis of the proportional equivalents between $^2/_{10}$ normal HCl, soda-ash, and lime we have

$$\frac{30 \text{ c.c.} \times 560^\circ}{\text{cubic centimeters of soda solution used}} = x^\circ \text{ of soda solution.}$$

3.4 c.c. = 2°
4.4 " = 3°
5.4 " = 4°
6.4 " = 5°
7.4 " = 6°
8.4 " = 7°
9.4 " = 8°

11.3 c.c. = 10°
13.2 " = 12°
15.1 " = 14°
17.0 " = 16°
18.9 " = 18°
20.8 " = 20°

It is sufficient if the purified water is perfectly clear and does not possess more than 5 to 8 German degrees of hardness; it must also form a foam, in the previously given dilution with chemically pure water, by the addition of 6 to 9 c.c. of soap solution.

9. On the alkalinity. As a prelude to the investigation of the alkaline strength of the pure-water colors 56 c.c. will be colored red with 2 or 3 drops of indicator according to (2); then drop in $\frac{2n}{10}$ HCl from a graduated burette, until the color change from red to yellow occurs.

Therefore 1 c.c. of $^2/_{10}$ HCl corresponds to 1° of alkalinity.

Pure water may not possess at the maximum an alkalinity of more than half its degree of hardness.

10. Investigation of raw water. The raw water is to be examined at stated times to determine its degree of hardness and alkalinity.

The result is to be entered in the operating note-book (see page 76).

It is recommended to take the tests of the raw water in different years, in time of drought, of rains, and of cold, in order to learn to know the peculiarities of the water under different outer conditions.

This control by the operator is necessary for the maintenance of the apparatus and in order that its successful operation may be independent of the attendant; besides this a properly timed mixture of the water with lime and soda-ash or other compounds at greater or less intervals of time is indispensable. The removal of the precipitate must also be properly timed.

OPERATING NOTE-BOOK.

Date.		Period.		Amount of Water Delivered in Cu M	Amounts Used.			Results of Examination.					Signature of the Operating Attendant Making the Tests.	Notes on Washing Out, Changing the Filter Material, Dissolving Lime, Testing the Chain of the Decanting Pipe.
Month	Day	Hour	Minute		Coal in Kg.	Soda-ash in Kg.	Slaked Lime in L.	Raw.	Pure.	Alkalinity.	Lime-water.	Soda-ash Solution.		
								Water.						
Of Operation.								German Degrees of Hardness.			Str'gth in Degrees			

If the owner or his agent can or will not always personally undertake entire charge of the water used in his establishment, at the least the attendant should undertake the most important tests, as follows: The determination of the total hardness, the determination of the alkalinity, the chemical strength and uniformity of the lime-water, and the soda solution; and the owner should be able to check up the tests.

If the attendant is in position to test the liquid himself, and if he can express the results of his tests in numbers in comparison with others, he will awaken an interest in himself for his work, he will deem himself better qualified, and the operator also will not lack the knowledge of the most important properties of water purification.

But if it is indispensable that the owner or his commissioner himself work in this department of his works, he must be in position to make himself all the tests of the water used in his establishment; he must be capable of calculating the time of changes of the raw water, the changes of the reagents used (lime-water and soda-ash solution); he must lastly be able to judge if the water-purifying plant installed works properly and uniformly.

If the subordinate feels himself firmly controlled, he will always perform his duty regularly.

In installed plants, the testing liquids should be taken out of definite receptacles, and the quantities should have strengths definitely determined.

It is well to carry out more tests with more and with less than the calculated amounts and compare the resulting purification together.

CHAPTER VII.

THE REMOVAL OF PRECIPITATE FROM THE TREATED WATER.

A WELL-PURIFIED water can form no boiler-scale; the latter at the most will be spongy from incomplete purification, and on letting out the water a spongy powder-like coating would form on the inside plates of the boiler.

On the other hand the removal of precipitate in the boiler will be hardly worth mentioning; the prevention and removal of this Prof. Kalmann described in the "Austria-Hungarian Journal for the Sugar Industry and Agriculture," Part I, 1902, (Oesterr.-Ungar. Zeitschrift für Zuckerindustrie und Landwirthschaft,) as follows:

If we treat a water according to the method of Berenger and Stingl with caustic lime and caustic soda, caustic soda alone, or with soda-ash and caustic soda according to its composition, and take for this treatment a properly calculated quantity of the reagents,* then the water obtained will not possess more than 2.5 to 5.5 German degrees of hardness, besides its other chemical properties.

A properly treated water behaves differently in the boiler from a natural water of similar degree of hardness.

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* For the calculation of the quantities of the reagents see Kalmann: Article on Water Treatment according to Berenger and Stingl, Communication of the Museum of Technology, 1890, (Beitrag zur Wasserpräparation nach Berenger-Stingl, Mitteilungen des k. k. technologischen Gewerbemuseums, 1890.) See also "Austria-Hungarian Journal for the Sugar Industry and Agriculture," Vol. XX, year 1891, page 130. (Oesterreichisch-Ungarische Zeitschrift für Zuckerindustrie und Landwirthschaft, XX. Jahrg. 1891, p. 130.)

In the latter the carbonates of calcium and magnesium (which form the temporary hardness) are for the most part thrown down, while the other calcium and magnesium compounds, which form the permanent hardness, will gradually accumulate in the waters, until saturation of these salts occurs, whereupon they will also begin to precipitate.

If we feed a boiler with a natural water of little hardness, a precipitate composed of carbonates separates itself, while the water in the boiler increases in hardness more and more until a certain limit.

I have had occasion, in time past, to investigate a water whose analysis showed:

Lime (CaO)...........	.0336	gr. per liter
Magnesia (MgO)........	.0038	" " "
Total hardness.........	3.9	German degrees
Temporary hardness...	3.1	" "
Permanent hardness....	.9	" "

After the boiler had been some time in operation, the water in the boiler showed a total hardness of 40.5°. It showed that the hardness of the water had increased more than ten times.

A water treated according to Berenger and Stingl behaves quite otherwise. In this the lime and magnesia are contained in the form of carbonates and hydroxides respectively, whose quantity varies according to the other salts dissolved in the water, as the solubility is different in pure water and water containing salts. The hardness of treated water is accounted for by the solubility of calcium carbonate and magnesia hydroxide, which, as we have mentioned, varies from 2.5 to 5.5.

If such a water is used for boiler feeding, it behaves like a saturated solution of lime and magnesia; therefore the strength of the lime and magnesia cannot increase any more. The lime and magnesia must precipitate themselves in the form of carbonate and hydroxide respectively, in the same quantity as the evaporated water is delivered.

I have the analysis of a treated boiler feed-water whose hardness was 4.8°. After 36 days' operation the water in the boiler showed only 2° of hardness, and the owner complained of the formation of a precipitate.

From Chief Inspector Wehrenfennig of the Austrian Northwest Railway, I have received a great quantity of treated water, whose analysis gives the following result:

Lime.	.0242	gr. per liter
Magnesia.	.0180	" " "
Total hardness.	4.9	German degrees
Temporary hardness. . . .	4.9	" "
Permanent hardness. . .	.0	" "

When a measured quantity of this water was concentrated to $^1/_{10}$ its volume, a precipitate was thrown down at once, while the filtered water showed the following composition:

Lime.	.0113	gr. per liter
Magnesia.	.0340	" " "
Total hardness.	5.9	German degrees

The composition has changed materially from the first, with which the proper proportion of reagents does not entirely agree, yet the total hardness remains about the same.

From both these examples it follows that a treated water acts differently in a boiler from a natural water of similar hardness. The following examples may demonstrate the disadvantage of these different actions.

Taking a natural water of:

Total hardness.	4.0	German degrees
Temporary hardness. . . .	3.0	" "
Permanent hardness. . . .	1.0	" "

the point of saturation is reached at 40° permanent hardness.

If we concentrate 40 cu.m. of this water to 1 cu.m., $30\times 40=$

1200 grams of lime and magnesia are thrown down respectively, while the water shows 40° of hardness.

1° hardness = 10 grams lime (CaO) per cubic meter
4° " = 40 " " " " " "

40 cu.m. water contains 40×40	= 1600 grams CaO
There remains in water of 40° hardness	400 " "
There was precipitated	= 1200 grams CaO

Or in the case of magnesia an equivalent quantity calculated to calcium.

If we concentrate a treated water of 4° hardness in the same manner, the water remaining will still always show a hardness of 4°; there must therefore have been precipitated 40×40 − 40 = 1560 grams of calcium or magnesia respectively, or 360 grams = 30% more than in the former case.

The question now resolves itself into how to proceed to improve a treated water in this condition.

The prepared water reacts in an alkaline manner with methyl orange, as does the natural spring and stream water.

If we saturate a treated water sufficiently with hydrochloric or sulphuric acid, a removal of precipitate will occur on carrying the concentration very far; on the contrary a substantial increase of the hardness would occur in the water in the boiler.

The use of an acid is very dangerous and only used in case a complete analysis is made continually; therefore for the same purpose the use of sodium bisulphate is recommended. Nitric acid may also be used for generating the salt mixture remaining in the water. A chemist must establish, by means of an acidity determination* of the treated water and the sodium bisulphate, how much of the respective amounts of the salt mixtures mentioned above must be added to each cubic meter of the water. If in practice we take a somewhat less amount, we will (notwithstanding the variableness in the treatment) not run the danger of creating an acid-reacting water.

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* Methyl orange as indicator.

One analysis which I carried out with sodium bisulphate and with a freshly treated water attained this completely. The water was neutral; it threw down no precipitate on concentration to 1/10 of its volume. The hardness increased from 4.9° to 49°.

If we stick to our former example, a treated water of 4° hardness and a saturation-point of 40°, we will precipitate by a concentration of from 40 cu.m. to 1 cu.m. $40 \times 40 - 400 = 1200$ grams lime or magnesia respectively; we have therefore the same result as with the natural water.

This behavior is advantageous because in a properly treated water the precipitation does not begin until the point of saturation is reached, while with a natural water the precipitation begins immediately. If, therefore, we do not continue the concentration to the point of saturation, whilst renewing the water in the boiler with fresh water, we can prevent precipitation.

It is clear that we may also achieve the latter object by the neutralization of a naturally soft water.

The following example may illustrate the proceeding:

Taking a water of 3° temporary and 1° permanent hardness. The point of saturation will be 40° of permanent hardness.

If we concentrate 20 cu.m. to 1 cu.m., $20 \times 30 = 600$ grams of lime or magnesia, respectively, will be thrown down.

But if by neutralization we bring the temporary hardness to 0, and the permanent hardness to 4°, there would be thrown down by a similar concentration only 400 grams of lime or magnesia, respectively, for $40 \times 20 - 400 = 400$.

The author has tried this treatment of neutralizing alkaline waters in small plants and obtained good results; but in large plants there is no advantage.

The use of sodium bisulphate would also only appear advisable if the apportionment of the solution would always result in a corresponding alkalinity according to the capacity and quantity of the apparatus, which would require a perfectly reliable person and a very exact apportionment.

The latter is possible, it is true, by means of the divided overflow and the soda displacement systems (see pages 88, 108, 109, and 114).

CHAPTER VIII.

THE ACCOMPLISHMENT OF WATER PURIFICATION AND THE SEPARATE ARRANGEMENTS EMPLOYED THEREFOR.

From the previous paragraphs may be easily calculated the kind and amounts of additions, from the results of the analysis of the water, which must be added to the raw water, in order to free the same of its chemical impurities.

It only remains to be decided how to prepare these additions and how to add them to the raw water, in order to accomplish the best possible purification.

For this certain devices are necessary, which will be described in the following.

1. Designations Selected.

The designation of the separate parts of the devices appeared in the previous edition so that every group of separate devices, which served a similar purpose, were marked with the same capital letter. This distinguished every part with the clearness of an index.

If this index indicated a receptacle, a small letter would be used; but if it indicated a pipe, an Arabic numeral was chosen and the uneven numbers 1, 3, 5, 7, etc., were used for inlet-pipes and the even numbers 2, 4, 6, 8, etc., for outlet-pipes.

The table of designations follows.*

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* The chosen designations were taken from the "Eisenbahntechnik der Gegenwart."

DESIGNATIONS OF PARTS OF DEVICES.

Raw-water introducing device	P	
by pumps	P	p
" pulsometer	P	s
" injector	P	e
" opening a steam-valve	P	d
" " " water-valve	P	w
Raw-water stop-cock or valve		a
Raw-water receptacle	W	
Preheater	T	
Steam-moving apparatus		d
Water distribution (for raw water, mixed water)	V	w, m
Water-space of the distributor	V	w
Pressure-regulator (for raw water, lime-water, soda-ash, or caustic soda)	D	w, k, s, ks
Lime distribution	K	
" dissolving-trough	K	l
" -pit	K	g
" filler-up	K	e
" -distributor	K	z
" -saturator	K	s
" -stirring mechanism	K	r
" -introducing device	K	f
" -pump	K	p
" clearing-plate	K	k
" bottom-plate	K	b
" washout-cock	K	a
" outlet-pipe	K	2, 4, 6, 8
Soda-distributor	S	
" solution-tank		l
" supply-chamber		v
" dipping-ladle		t
" -water air-regulator		w
" air-regulator		s
" gauge-glass		g
" -pump		p
" air-pump		m
" pressure-regulator		d
" flexible tube		b
" -siphon		h
" washout-cock		a
" outlet-pipe		2, 4, 6, 8
" inlet-pipe		1, 3, 5, 7
Caustic-soda tank	KS	
" distributor		z
" solution-tank		l
" air-pump		m

DESIGNATIONS OF PARTS OF DEVICES—*Continued.*

Overflow	U	
Tilting-vessel	H	
" with stirring-paddle		s
Air-pipe	L	
Air-deflecting surface		f
" plate		p
Filter	F	
Stirring mechanism		r
With excelsior		h
" sand		s
Mixing-chamber, clearing-chamber	M	m, k
" " washout-cock	M	a
Pure-water chamber	R	
" " washout-cock	R	a

2. Preparation and Introduction of the Reagents.

In the "lime and soda treatment" here mentioned, the addition to the raw water is best made in the form of solutions (lime-water, soda-ash solution, caustic soda), as the most thorough mixing of the liquids is then possible and the strengths of the reagent solutions are most uniform.

The quantities of liquids necessary for the purification are taken from the raw water as it enters.

The results must correspond with an analysis, as the strength of chemicals in the reagent solutions is known; therefore, bearing in mind this strength, a certain proportion is to be maintained between the quantities of liquid solutions taken from the raw water to the quantity of raw water entering the apparatus, which is to be constant so long as the composition of the water remains the same.

This proportion must be capable of being maintained at all times and therefore must be easily controlled. As the strength of the regeant solutions is very easy of proof, as we have already shown, it is necessary to have an adjustment by which it is possible for the amounts of the liquids to be very easily regulated at any time.

The best results are obtained if we allow all the water to flow over a horizontally placed brim and have the length of this edge divided by partitions to correspond to the desired proportions, so that the different quantities thus separated flow off by themselves.

Then the proportions of the liquids will be fixed according to a standard scale and the exact quantity of the different liquids will overflow.

A. Water-Distribution.

One such divided overflow-distributor, known as the Wehrenfennig System, is shown and described as follows:* (Oest. Priv. $\frac{49}{842}$, $\frac{14}{1}$ 1899.)

The problem is to divide the total quantity of raw water simultaneously into three parts according to the proportions determined by analysis or into

a. which mixes with the reagent solutions and changes from raw water to pure water;

b. the raw water used in the preparation of a clear saturated lime-water, which water flows direct through the lime;

c. the raw water used to displace a similar quantity of dissolved soda-ash or caustic soda, and which is only used for this work.

If the water is to be divided in four parts, as, for example, to wash out the tank, the principal of the adjustment is not changed.

The distributor *V* (Fig. 12) consists of a circularly formed vessel through a sieve, and over whose edge the quieted raw water flows from the delivery-pipe P_2 into an annular space. The circumference of the edge of the overflow is properly divided by projecting partitions 1, 5, 3, so that raw water flows into the separate chambers 1–5, 1–3–3–5, 3–3, maintaining all the time the proper proportions of the various quantities according to the composition of the water to be purified.

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* Later Breda and Harris Anderson have used overflow-weirs divided underneath. Breda a rectilinear, Harris Anderson a circular.

The largest chamber 1–3–3–5 of the distributor delivers the allotted raw water to the purifier through the pipe 2; out of the smaller annular space 1–5 raw water flows through the pipes 4 and 6 to the lime-tank.

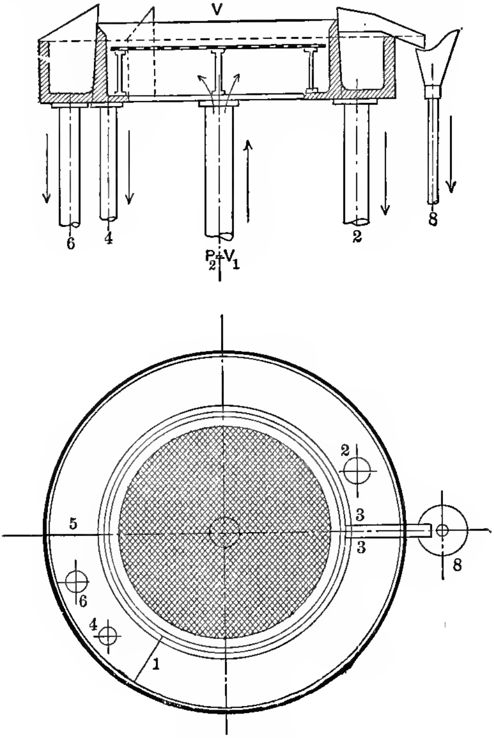


FIG. 12.

The small chamber or gutter 3–3 of the distributor delivers a quantity of raw water through the pipe 8 to the soda apparatus.

The water distribution by means of a cock or valve, either arranged singly or in groups depending on each other, is decidedly less worthy of recommendation than this divided weir; for, while in the weir a small change in position of the dimension causes a small change in the quantity of raw water passing over, while with valves or cocks a small change in the position causes a great change in the quantity flowing through.

Besides, this predetermined proportioning of the distribution is guaranteed by the weir whether the pump delivers more or less water, and this is better than with valves or cocks, where the contraction of the passage of the water with its uncertain obstruction has great influence on the quantity passing through. A continuous standard cannot be maintained in any case with cocks or valves as controllers, while with the weir the result is perfectly standardized.

But the superiority of the weir distributor over the previously mentioned cocks or valves would not be fully and completely brought out if that part of the raw water which causes the outflow of a similar quantity of soda-ash or caustic soda solution did not effect this latter work in a simple manner.

The water trickling from this arrangement causes the sinking of a plunger, which causes the displaced liquid reagent to flow out; or the water may enter an air-regulator whose air-space is in communication with a second air-regulator filled with the liquid addition, and by this the latter will be raised, according to the amount of water admitted, to the point where the mixing takes place.

Both these arrangements are much more to be recommended for water-purifying plants than the use of cocks or valves, but it is not intended here to expatiate on the deficiencies of cocks or valves.

If cocks or valves are used, the head under which the liquids flow out must remain in an absolutely constant relation to each other.

If, for example, as is the case in the Berenger apparatus, the raw water constantly required and which is to be maintained constantly at the same height in the tank (*V*) by an overflow (*U*) should be mixed in the chamber (*KS*) with the mixture of lime-water and caustic soda already placed in it (the so-called reagent-water), a pressure-regulator (*D*) must be used, which will make possible the discharge of the reagent-water from the outlet-cock under a fixed constant head.

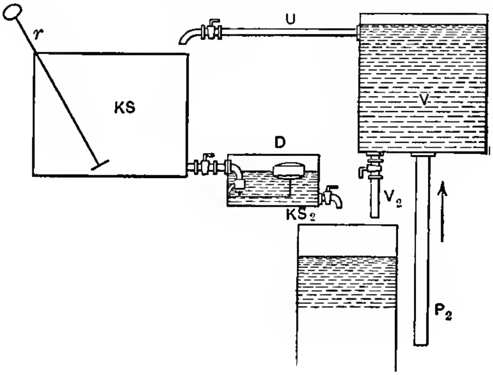


FIG. 13.

If the soda solution, instead of being mixed in the chamber *KS*, should be prepared by itself and should flow to the point

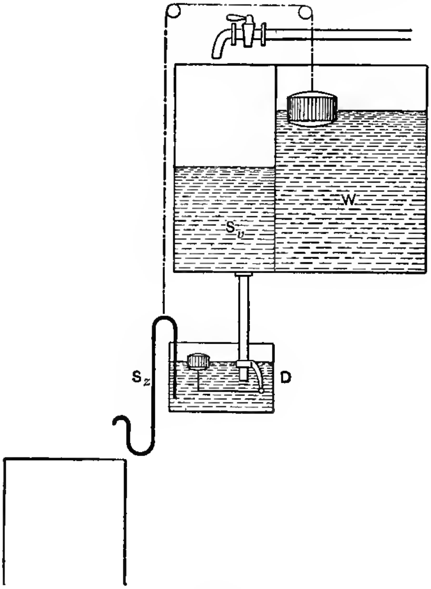


FIG. 14.

where mixing takes place, a similar pressure-regulator must be used, or it will be necessary, as in the case of the Derveaux apparatus, to draw the soda through a siphon (*h*) from the soda-tank (S_v) by means of a float and a siphon floating in suspension on the surface of the raw water (see Fig. 14), or the soda will be delivered through a flexible pipe (*b*) (Fig. 15) to whose end a cock is attached, which is raised and lowered by a float in the same manner, so that the liquids flow out under a constant head when water is contained in tank (*W*).

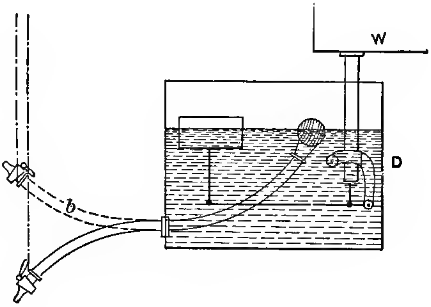


FIG. 15.

The outflow of soda ceases with the stoppage of the inflow of raw water.

B. Preparation of the Lime Addition.

The burnt lime is the best and can be used in the most economical manner if it is freshly dissolved.

But as we require for the daily water purification only a small quantity of lime, and as a greater store of burnt lime would fall to pieces, it is better to give up all claim to the maximum efficiency of the lime and procure the lime in larger quantities, dissolve it immediately, and store it away in a lime-pit.

We will then have a somewhat less efficient but constantly uniform supply of lime. As the lime is cheap and for this reason and—because water only takes up a definite quantity of it—a surplus can be used so that a daily measurement of the lime charge by weighing is not necessary and the dose may be easily gauged. This dose is so calculated that it will last from 4 to 6 hours.

Open lime-tanks will be filled directly from the top (Fig. 16); closed lime-tanks, on the contrary, will be filled from a similarly closed main tank out of which it will flow gradually into a lime-chamber (Figs. 17 and 18).

In order to prevent any stoppage (of the lime-carriers K_z) in consequence of the introduction of lime into the bottom of the receiver, the cross-section of the water inlet-pipe is so designed that at the same time a corresponding quantity of air will rush down with the water.

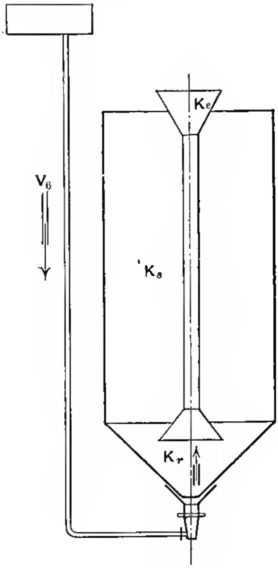


FIG. 16.

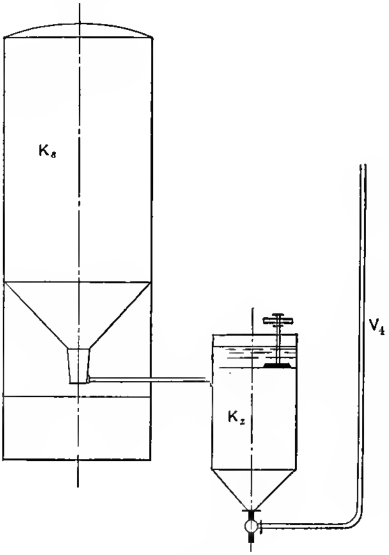


FIG. 17.

This air simultaneously causes a violent stirring of the lime in the receiver and in the lime saturation-tank (K_s) by rushing in through it.

The distribution of calcined powdered lime in a mechanical manner by means of belt conveyors, spiral conveyors, or rolls is not worthy of recommendation, because, in consequence of the hygroscopic properties of lime, the moving parts of the former will be incrusted, causing resistance which will bring the said apparatus to a standstill.

Saturated clear lime-water may be very easily produced, if we stir in by hand 1 kg. burnt lime = 4 liters thick lime paste per 1 cu.m. of water and then leave settle, or if we take lime in a funnel-shaped receptacle or in one with a funnel-shaped bottom and allow the raw water to flow in through the lime from below.

If the shape of the funnel is steep enough, the undissolved lime falls down again and again against the rising water and will be deprived of its strength.

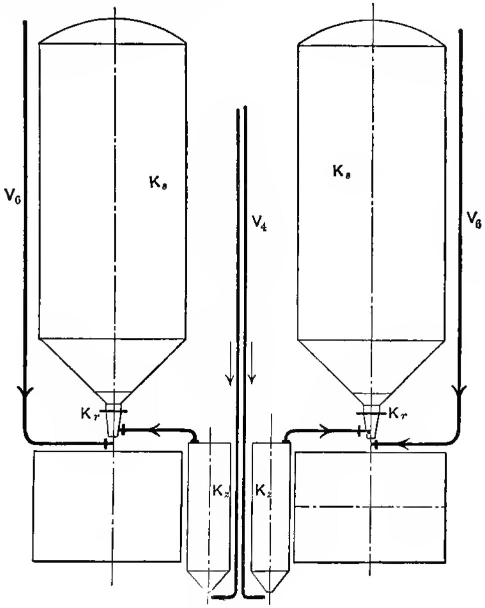


FIG. 18.

By a current rising in this manner through the milk of lime found in the lower part of the receptacle, the upper portion of the receptacle clears itself of milk of lime and the water then flows from the top as clear saturated lime-water with a strength of 120° to 125°.

The water cannot take up more than this 120° to 125° from the excess of lime present, and therefore the use of lime-water is peculiar in that the regularity of the quantity of lime added is guaranteed.

But this clear discharge is only continuous if the inflowing quantity of water does not exceed a certain limit and the velocity of the rising water is not too great over a known period. A cloudiness of the discharging lime-water is often apparent two hours after admission, which may not be permitted, as then there is no gauge for the excess strength of lime in the water. This is carried along with the dissolved caustic lime, and the inefficacious undissolved particles of caustic lime are carried over as $CaCO_3$ in the suspended matter in the water, which increases the desired strength of 1.20 to 1.25 grams per liter of water and therefore leads to an excess of lime being added.

One of the most important problems of the builders of water-purifying apparatus is now to proportion the dimensions of the receptacle for preparing the lime with the quantity of water passing through the same, and to make the stirring of the lime in the water passing through so violent that not only will a complete saturation occur, but also a continuous clear discharge of lime-water will be maintained.

On account of the small solubility of lime with water, the saturation of the latter can only be achieved when the lime is distributed through the water by the most energetic swirling motion and stirred up with the water.

For this purpose those stirring-tanks in which this swirling motion was caused with great energy and given a hand stirring besides, as was the case in the lime-recéptacle of Berenger & Stingl, are now almost entirely superseded by the settling process in water-purifying arrangements now working.

I. The efficacious mechanical means by which the swirling is caused are:

a. By means of rotating stirring-arms (Fig. 19).

b. By means of stirrers moved up and down (Fig. 20).

But these mechanical stirring devices require a motive power which is not always at hand, or water-wheels which may be operated by all the water as it enters, but are subject to derangements.

II. Hydraulic means which cause swirling motion are:

a. By means of strong current in the lowest part of a narrow chamber or one having a conical form (Fig. 21).

By pouring in water in the wider portion the operation does not take place. For this reason and because the lime placed in the funnel should be used up, the water-inlet must be made as low down as possible.

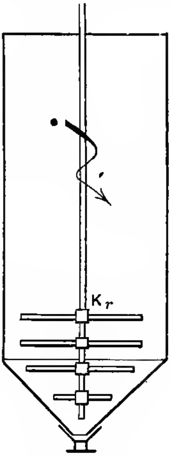


FIG. 19.

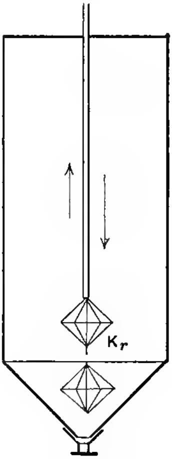


FIG. 20.

b. By means of an eccentric inlet of water (Fig. 22), in a receptacle with a narrow cross-section and an axially central outlet used by Wehrenfennig, s. D. R. P. 96091, for mixing and later used by Breda in a lime-saturator. In later systems a whirling motion in horizontal strata was produced by means of an oval cross-section).

c. By means of a vertically washing up and down of the lime particles in cross-sections changing from wide to narrow (Fig. 23).

III. Pneumatic means (Figs. 16–18) which employ a rising current of air in the water for stirring are independent of the form of cross-section of the lime-receptacle. The lime-particles are energetically stirred up to any desired height with the water from one or more jets (from below by K_r, and from above by K_c). The air necessary for this purpose will be constantly carried automatically in by the entering stream of water in a closed pipe. (System Wehrenfennig Oest. Priv. $\frac{49}{842}$.)

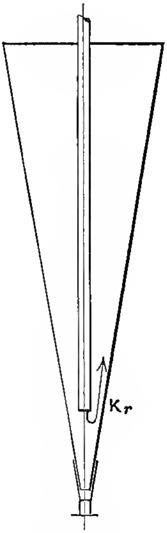


FIG. 21.

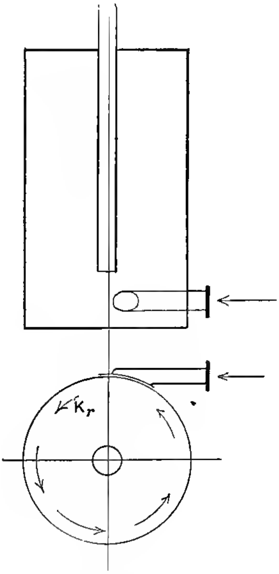


FIG. 22.

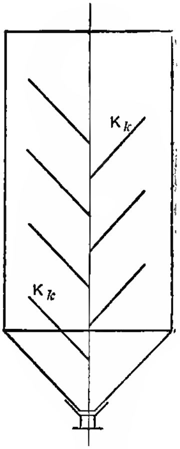


FIG. 23

The employment of air for the saturation of the water with lime is of particular advantage, because the rising currents of air (v) in the water remain the same in narrow as in wide lime-receptacles and because they will not be divided or be hindered by inlet-pipes. The most violent swirling and circulation will be imparted to the water by this means.

For water alone (Dervaux System) the rising currents are dependent on the cross-section of the lime-receptacle. A very important point in the employment of air is the keeping clean of the outlet orifice of the lime-outlet and the positive inlet of air in spite of obstruction, because the head will increase rapidly in the open topped inlet-pipe from the distributor, and on this account the water and air will rush violently through any choked-up places of the inlet openings into the lime saturator.

Such a continually operating automatic stirring apparatus first using air was that of E. Wehrenfennig,* in which the water passing down a narrow pipe rushed with a great quantity of air to the bottom of the mixing-vessel and rising stirred the lime energetically with the water. Air is carried with the water when the area of the downtake pipe is less than $Q/2.2$ square decimeters, wherein Q is the quantity of water in liters and 2.2 decimeters indicates the velocity of a rising air-current in the water. It will be observed that the air rises in groups of bubbles in the water, does not remain under pressure in the latter, and frees itself in great bursts.

There can hardly be, therefore, any absorption of air by the water, as the following tabulation of the results of analyses shows that the stirring of water with air in the manner described above does not result in its taking up oxygen.

The water in the distributor, the water in the inlet stirred with lime by passing air through it, the water stirred with lime in the lime-saturator, and the pure water were examined for their strength in oxygen by the Agricultural Chemical Investigation Station in Vienna (II. 1. Trunnerstrasse 3) and gave the following per 1 liter of water at 0° C. and 760 mm. barometric condition:

Anal. No. 567 A,	water from distributor.....	6.32 c.c. oxygen
" " 569 A,	" " inlet..............	5.83 " "
" " 568 A,	" " lime-saturator.....	5.87 " "
" " 570 A,	" " pure-water reservoir	5.83 " "

---

* Later Breda has used an air-stirring apparatus by which the water flows in a tipping-chamber and by the turning over of the latter air is carried along through the outlet-pipe. Harris Anderson has also used air.

There has therefore taken place no absorption of oxygen by the water, but, on the contrary, a decrease in the oxygen strength has occurred.

The water in the distributor was drawn from a depth of about 3 meters below the upper surface of the water in the well.

The water taken from the surface of the water in the well contained only 4.9 c.c. oxygen, and this water had stood for a very long time.

The air contained in the water, to which condition has been attributed the corrosive action on the iron, will therefore not be increased by the use of an air-stirring device.

The harmlessness in this form of admitting air is shown also by the fact that no unfavorable experience has occurred yet in this respect in the operation of large pumps.

If this method of mixing with air were harmful, how much more harmful an action on boilers would be caused by a brook water, where a mountain brook, whose water falls over rocks again and again and thereby becomes more and more mixed with air and the water richer in air, is used, but experience shows this is not the case.

Therefore no objection can be raised against this way of stirring with air.

The carbonic acid of the air will unite with the lime and therefore this tendency of introducing air into the water and into the boiler has no harmful results.

The liberated air of the tank in the stirring-space will be freed in the upper part beneath a wide funnel and escape through a pipe leading from the top of it.

The lime-charge issues either from the upper end of this pipe, or the lime is forced out of a special closed lime-vessel by means of a corresponding quantity of water.

In all the cases given above, the clearing of the lime-water occurs during the gradual rise of the entering liquids in either rectangular or cylindrical tanks, whose bottoms are either conical or funnel-shaped or in slender conical tanks, so that thorough and easy removal of precipitate will be secured.

In this type of saturator the lime-particles washed up must fall back again.

The wider, the greater, and the higher these clearing-tanks are in proportion to the quantity of water passing through, the quicker and more continuous will the clearing be.

If by long-continued operation, even in very high tanks, the exhausted as well as the still useful lime is carried to the top, the strength of the cloudy lime-water flowing out will be higher in calcium hydrate than 1.2 grams per liter. Therefore in such cases corresponding precautions must be taken in order to obtain the delivery of a uniformly effective lime-water.

To make a continuous and regular operation possible either a large lime-chamber must be used allowing a length of time for the water to pass through proportional to the length of time the plant operates, or several lime-chambers must be used, placed one behind the other, in which the particles of lime carried along will settle (which is not very economical), or two lime-saturators must be used alternately), or a lime-saturator should be so arranged that an alternate clarification and a continuous outflow of lime-water could take place from it.

In the following sketches (Figs. 24, 25, and 26) is shown a working lime-chamber, very effective, open at the top and with an air-stirring device, described as follows:

It consists of a chamber which is divided in two parts, (*I*, *II*) by a partition reaching not quite to the bottom. In the middle is placed a pipe, at the top of which is a funnel (K_e), and at the bottom a funnel (L) for an air-outlet, and in it is placed vertically the movable pipe (K_1S_1). The funnel is separated from the middle pipe by a screen bottom-plate (b). In this funnel is placed the lime-paste.

The lime-chamber holds a quartz filter K_f on top, and in middle space plates K_k are placed obliquely. The lowest part forms a precipitate-chamber K_r. Into this the pipes V_4,

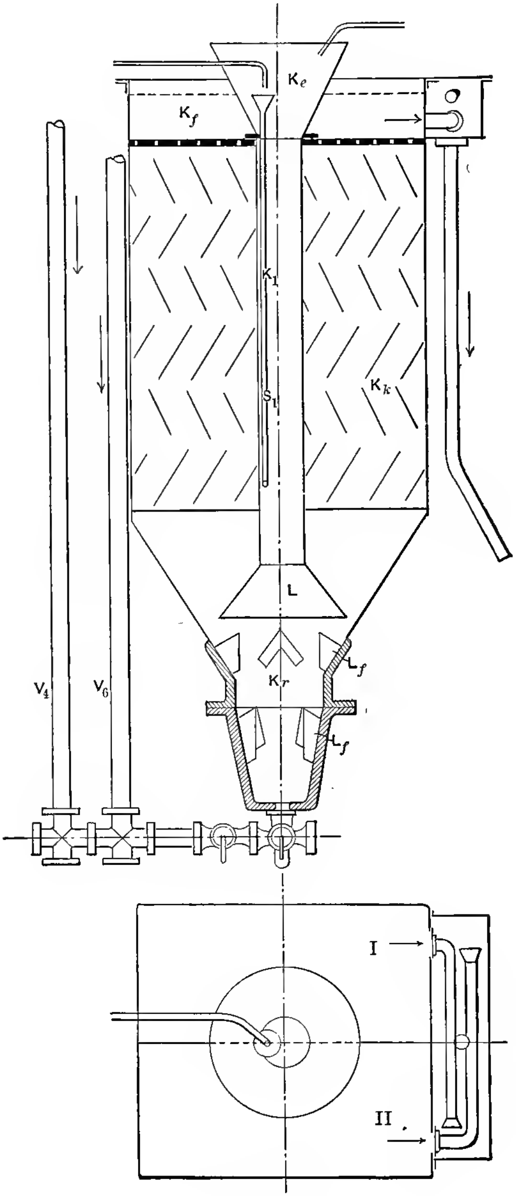


FIG. 24.

V_6 connect from below, which convey the raw water necessary for the preparation of the "lime-water."

With the latter will be carried in a certain quantity of air, which disengages itself in the bottom of the precipitate-chamber and by its rising causes a great agitation.

The rising air will pass through the oblique deflecting-plates L_f placed in the precipitate-chamber, to the air-outlet funnel L on the lower end of the middle pipe, and then rise through this central pipe.

A deflecting-plate L_p is provided on the bottom of the pipe K_1S_1 so that the air cannot enter the same and escape. The air is now compelled to rise in the central pipe through the screen, plate b and then to pass through the lime-paste placed in the funnel K_e. The latter is continuously stirred up by this means. In consequence of the agitation thus effected it flows gradually down through the large pipe. The necessary lime thus reaches the lower part K_r of the lime-chamber and, being kept here in continual agitation by the rising current of air, will be finely divided, so that the water will be completely saturated with lime.

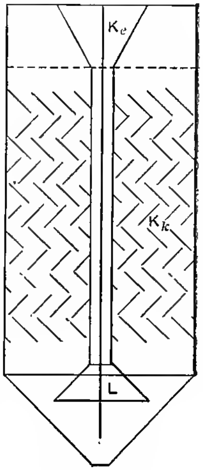


Fig. 25.

By the agitation and by a stream of soda-ash or water from the pipe S_2 as well as W_2 a slight excess pressure will be caused, which forces the lime down to the stirring-apparatus. If the soda solution is not brought to the lime-agitating apparatus, the raw water, carried to the point of mixture with the lime-water, passes through the pipe S_2, K_1, S_1. The entering water then flows through the pipe W_2 from a tilting-vessel (as we will see later). In Figs. 27, 28, and 29 is shown the arrangement of a three-way cock for the working-chamber, washout-place, and lime-receptacle (marked a_1, a_2, a_3, respectively).

The distance and the time in which the cloudy particles

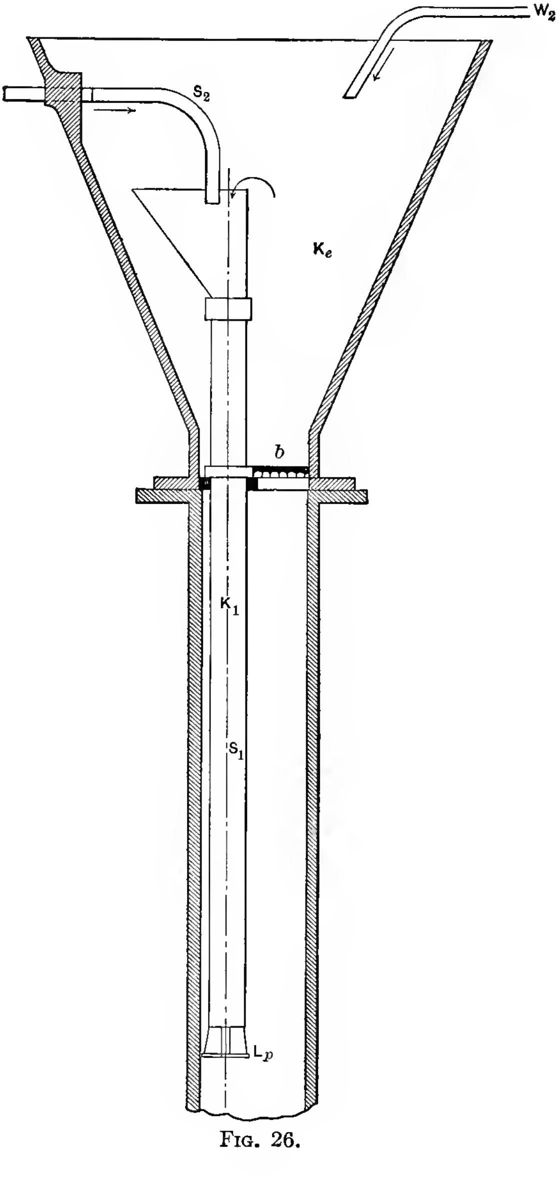
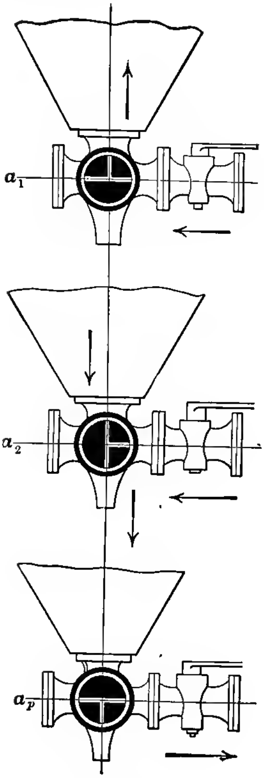


FIG. 26.

sink down, will be diminished by means of easily removed plates K_k placed at an angle of 45° at half intervals (see Fig. 30). The clarification will be assisted by these, as the flow of precipitate sinking down and the rising pure water cannot oppose each other.



FIGS. 27–29.

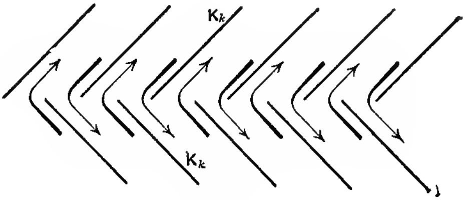


FIG. 30.

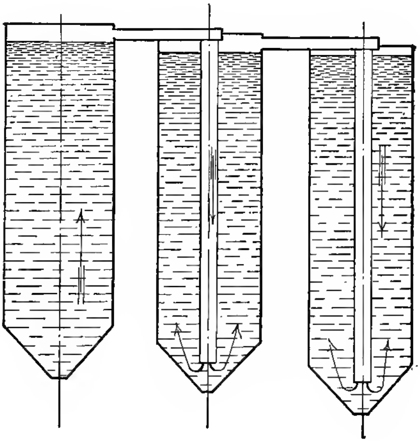


FIG. 31.

The possibility of a continuous clear discharge of lime-water with a single lime-tank and a continuous operation, for ten hours for example, is only secured when the clearing height of the lime-tank is not too small and when the velocity of the rising current of water is not too great. It is especially recommended that the clearing height be 3 meters and the velocity of the rising current be .2 mm. per second at the minimum.

By lime-tanks placed in series (Fig. 31) the velocity of the rising current may be .4 mm. per second, if care is taken that the liquid undergoes just as many inversions as there are tanks, as then the suspended particles on account of the velocity will be reduced to nothing. A greater part of them remain behind at each inversion and are not carried on.

By alternating the direction of passage and with a sufficient height of the tanks (3 meters or thereabout) a velocity of current of .5 to .7 mm. per second may be used to secure a continual clear discharge of lime-wâter.

By an alternating treatment of the water in one or in two lime-tanks or lime-compartments when quiet a more rapid clarification is obtained than if the water is flowing continually.

This simultaneous changing of the direction of passage of the water in two compartments, respectively, is shown in the tilting-vessel constructed by Wehrenfennig in the year 1895.

The tilting-vessel (Fig. 32) is an apparatus the purpose of which is to alternately take away from these compartments I and II the lime charge formed in the lime-tank, or to alternately cause the discharge from two lime-water tanks.

By this method the lime-water to be added, besides being always in one compartment, is still, and therefore clarifies quickly.

The tilting-vessel alternately lifts and lowers the movable outlet-pipes H_2 and H_4 conveying the water to be added from above the gravel filters, and out of both spaces of the lime-water tank, so that lime-water may alternately flow away from each space.

This alternate raising and lowering of the flexible pipes H_2 and H_4 will be caused by the two chambers *B* and *B*, fastened to the ends of a double lever, and with the outlet-pipes, by means of wires, being alternately filled and emptied of water.

The filling occurs through the turning over of an open prismatic tipping-vessel *H* by the inlet of water through the pipe H_1 at regularly determined intervals.*

According as the vessel turns over quickly to one side or the other, and alternately empties out its contents into either receiving-vessel *B* or *B*, and as these become alternately heavy, the pipes raise or lower themselves in a similar manner.

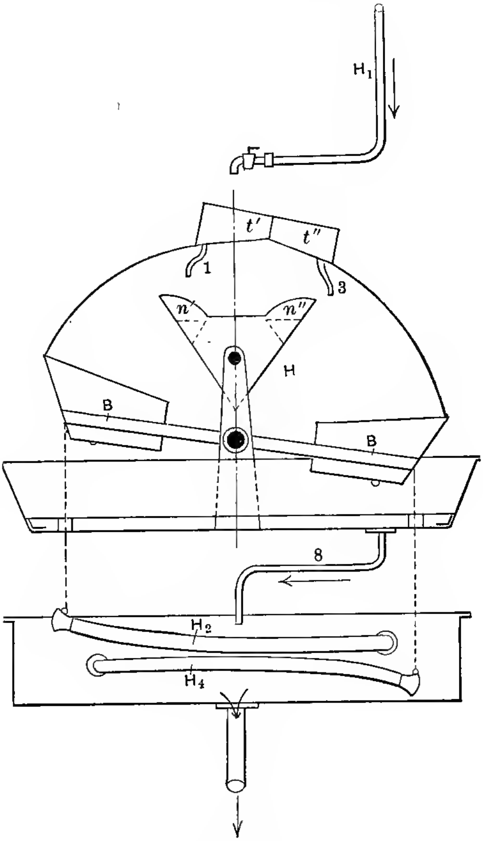


FIG. 32.

The variation of the direction of the turning over will be controlled according as the entering water flows from the pipe H_1 through a cock over the middle of the tilting-prism alternately into either of the basins n' or n'' fastened on either side walls of the prism, from which the tilting-chamber receives a corresponding overweight, causing an easy dipping to one side or the other. By this means the turning over will take place quickly from one direction to the other.

---

* Tipping-tanks of this description were later used by Breda for the division of the soda-ash.

From the alternate admission of water it follows that it will be conveyed into two vessels attached to the double lever, and from the outlet cock by means of small pipes into the small cups t' and t'' shown, and through pipes 1 and 3 into the corresponding basin of the tilting-vessel. The cock, through which the water enters, should be so adjusted that the tilting-vessel will turn over every 20 to 25 minutes.

As the turning over takes place very quickly, in order to prevent the discharge of the water to be added splashing out, it is allowed to flow out slowly through the open drain.

If the operation and attendance of the lime-tank is to take place from the ground level, then it must be completely closed (see Figs. 17 and 18)

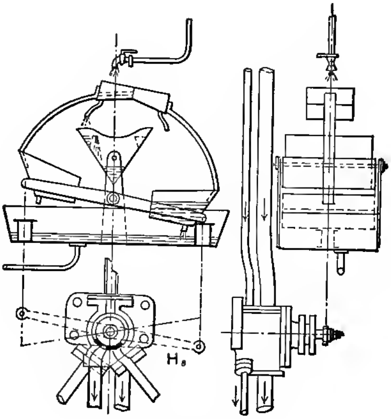


Fig. 33.

With such a closed lime-tank the tilting-vessel will be necessary for the operation of a stirring device, which will be placed in the entering current of water to the lime tanks. The tilting-vessel will be connected with this stirring device from the double lever. The stirring device H_2 is shown in Fig. 34 to a somewhat larger scale and causes the reversal of the water entering the lime-dividing tanks and the lime-saturating tanks.

It is to be noted that the water for dissolving the lime should have only the usual temperature, since the lime is less soluble at higher temperature than at the ordinary temperature. According to A. Lamy the percentage of calcium hydrate soluble is

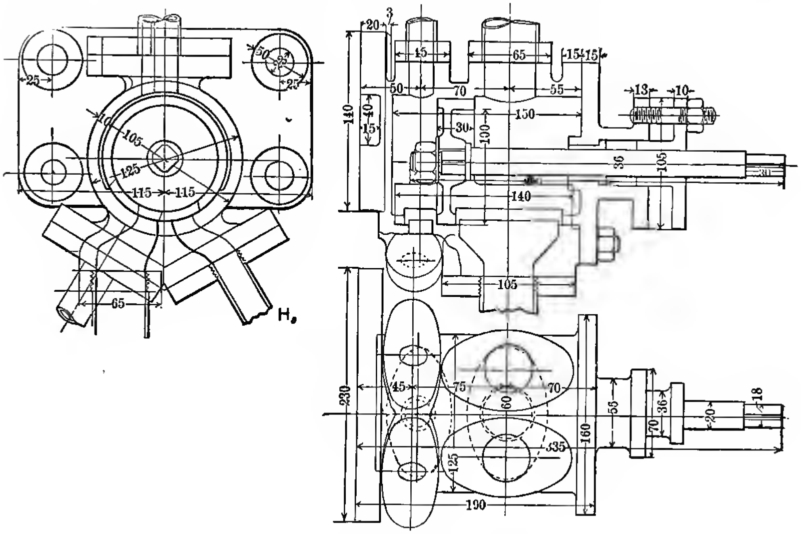


Fig. 34.

.143 .1384 .1344 .1195 .1033 .0885 .0584

at a temperature of

0° 10° 15° 30° 45° 60° 100°

C. Preparation of the Soda-ash to be added.

For the preparation of the soda solution we use usually only calcined or ammonia soda having a soda strength of 96 to 98%.

The storing of the soda must be done in dry rooms in closed tanks.

While we bring the necessary raw water in direct contact with the lime for the preparation of saturated, clear, uniform lime-water and can even cause an excess of lime, it is not possible to produce a soda solution of always uniform strength if we allow the raw water to flow through the soda in the same manner as with the lime, as the water will dissolve different amounts of soda, according to the temperature and amount of soda present.

The soda must therefore be dissolved in the usual manner by dissolving a determined weight of soda (crystallized 36% or calcined ammonia soda about 98%) in a definite quantity of raw water.

A stirring of the soda with the water is not necessary, according to the experience of the author, if we spread out the soda uniformly on a fine sieve and allow it to be moistened from the water standing below.

By this method the heavy soda solution sinks to the bottom, forcing the unsaturated water to the top, where it then takes up soda. This automatic cycle continues until the whole of the soda is dissolved. By this economical method an absolutely uniform solution is obtained without hand-mixing.

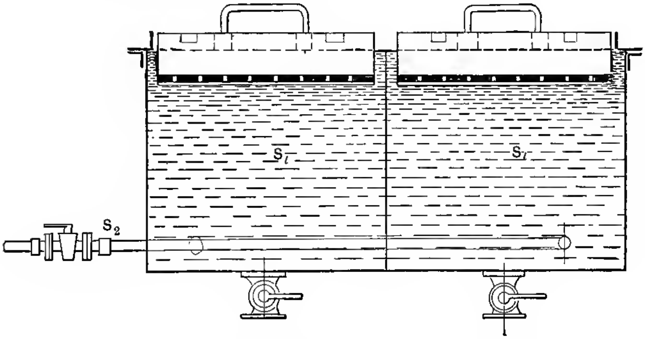


Fig. 35.

In the usual early method, the solution of the soda was made by placing a perforated crate of soda, through which the water passed, on the bottom of the soda-tank, but with this method it cannot be dissolved without stirring.

The soda solution will be alternately prepared in two troughs S_1 and S_1 (Fig 35), in which the expensive crystallized, the calcined, or the ammonia soda will be evenly spread out on the sieves and dissolved by the water standing beneath.

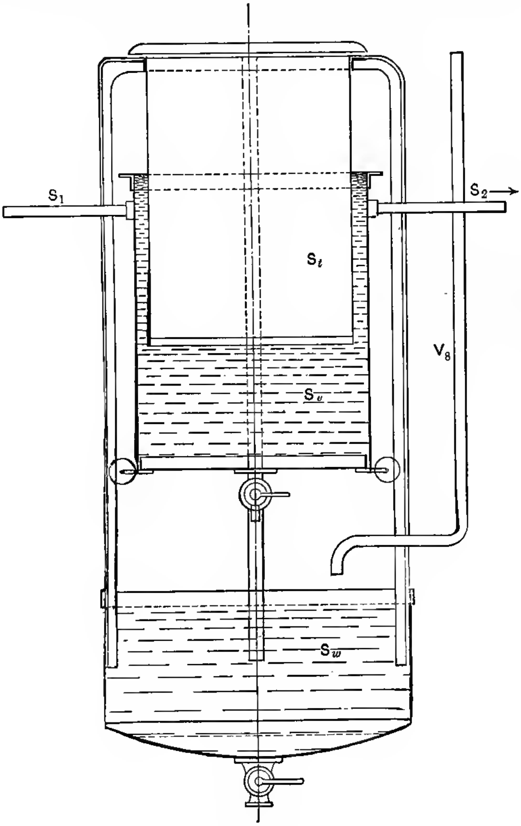


FIG. 36.

The soda solution thus prepared flows to the open lime-saturator through a pipe S_1 into the chamber S_v of the soda-distributor. Into this dips the piston-shaped tank S_t, which is connected on either side with the water-chamber S_w.

The proper quantity of water flows from the distributor V (Fig. 12) through the pipe 8, which according to calculation is equal to the amount of soda solution necessary to be added to the lime-water, and, as we previously remarked, is only taken from the distributor V to accomplish this work.

In proportion as the interior of S_w is filled by this water it sinks, drawing down the piston S_t, and the latter forces a similar quantity of soda solution out of S_v through the pipe S_e to the lime-tank (Fig. 26), in which it mixes with the lime-water.

We may also use with advantage the following soda-measuring apparatus (Fig. 37), in which the quantity of soda solution (caustic soda solution) flowing through it is dependent on the amount of raw water flowing over the distributor.

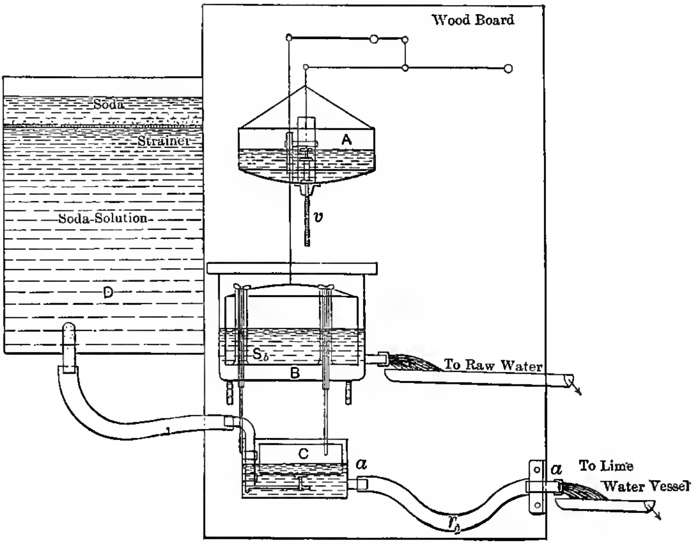


FIG. 37.

This soda-measuring apparatus begins to flow almost at the same time with the overflow of water; by the stoppage of the overflow it ceases to flow. Besides, in practice the increasing quantity of water flowing over causes a similar increase of soda discharge, so that at all times the quantity of soda flowing out is proportional to the quantity of water flowing in.

The theoretical principle, by which this action is obtained, is that, with the same head and the same outlet openings, equal amounts of discharge will be obtained. The previously mentioned apparatus is based on this principle, and must fulfill the further condition, that the quantity of outflow of the soda must be dependent on the position, at any time, of the surface of the water in the soda-tank.

These conditions cause the production of a solution, as will be described:

The distributing apparatus consists of the receiving vessel *A* shown with a valve in the bottom, which is connected by means of a float and levers with a float S_v to be found underneath. The float is placed in a fixed tank *B* with a fixed outlet pipe, as shown, and operates a pressure-regulator hose *C*, with which it is connected by three small rods, into which the soda solution flows from the soda solution collecting tank *D* through a flexible pipe r_1, and from which it flows out through the flexible pipe r_2, and the fixed discharge opening *a*.

Working of the Apparatus.

The water flowing out of division 3 of the water-distributor collects in the vessel *A* until the weight of the vessel, together with the water, becomes so great that the vessel sinks, the valve-rods push on the top of the raised float through the levers, and cause water to flow into the tank *B*. By this the surface of the water rises in the tank *B* without loss of time, and the float takes a correspondingly higher position on account of the filling of tank *B*, which after a few minutes will be made constant by the valve remaining open, and result in a discharge corresponding to the head and area of the discharge opening. With the raising of the float the pressure-regulator *C* hanging from it is raised, and the soda solution is brought to the discharge.

As there is a float with levers in the pressure-regulator, which, rising with the rising surface of the soda-solution, shuts off more of the outlet opening from the soda-collecting tank, or by the lowering of the surface opens it more, and the level of the soda solution is a constant one for all ratios between the different positions of the soda solution in the collecting tank and the pressure-regulator chamber. As the outlet of the pressure-regulator hose is fixed, and the pressure-regulator hose will be raised to the same height as the upper float, the heads in both chambers theoretically must be absolutely equal, and therefore the quantity flowing out of the water-chamber be exactly equal to that out of the pressure-regulator. But on account of the friction in the lever arrangement, on account of the incomplete flexibility of the hose, etc., the float in the water-chamber lags somewhat behind the rising of the water in the water-chamber, and therefore the head of water in the water-chamber will always be greater than the elevation of the float itself. Therefore the area of the soda outlet opening must always be somewhat greater than that of the water, and this is accomplished, in the usual form of the apparatus, by a corresponding restriction of the outlet opening *a*.

Adjustment.

The adjustment of the apparatus is made in the following manner: The weight of the float and that of the pressure-regulator hose is made somewhat greater than that of the bowl. The point of admission will be found first by waiting until the float apparatus floats of its own buoyancy, with no discharge from the water outlet; by this will be ascertained the proper height for the soda outlet opening. The valve-spindle is to be so placed that the valve will be opened the minute as much water runs into the bowl as will cause the corresponding head in the float tank.

To the apparatus will be added three pairs of outlet plates, of which the pair with the greatest hole is to obtain the maximum outlet, the second for the medium, and the third for the minimum quantity. Each pair of plates permits a variation of 20% in the quantity discharged, and with perfect accuracy. For a greater variation the pairs of plates are changed.

A similar type of soda-distributor, dependent on the quantity of water flowing over the edge of the distributor, is shown in Fig. 38.

The soda will be dissolved in the vessel S_1 and let flow into the vessel S_v placed underneath.

The water falling from the distributor enters the vessel *W*, and flows out of this through a correspondingly narrow pipe. By a greater or less inlet, the float in this vessel raises or sinks.

This float is so connected by a chain over rollers with a second float in the vessel S_v and a flexible hose that, during the passage of the soda solution, it flows out under the same head all the time.

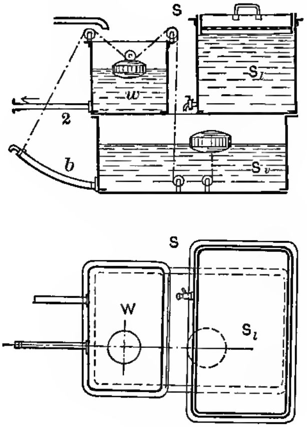


Fig. 38.

If the inflow from the distributor ceases, the float in the vessel *W* sinks, the water flows through the discharge outlet, which is always open, and the flexible hose is raised so that no more soda flows away.

Besides the above-named soda-regulating devices, which cause the definite mixing of the raw water and reagents, there remain those in which a tilting-vessel operated by a part of the raw water is used so that, every time it turns over, a certain quantity of soda solution is scooped out.

There remains, too, the closed apparatus where we pre-

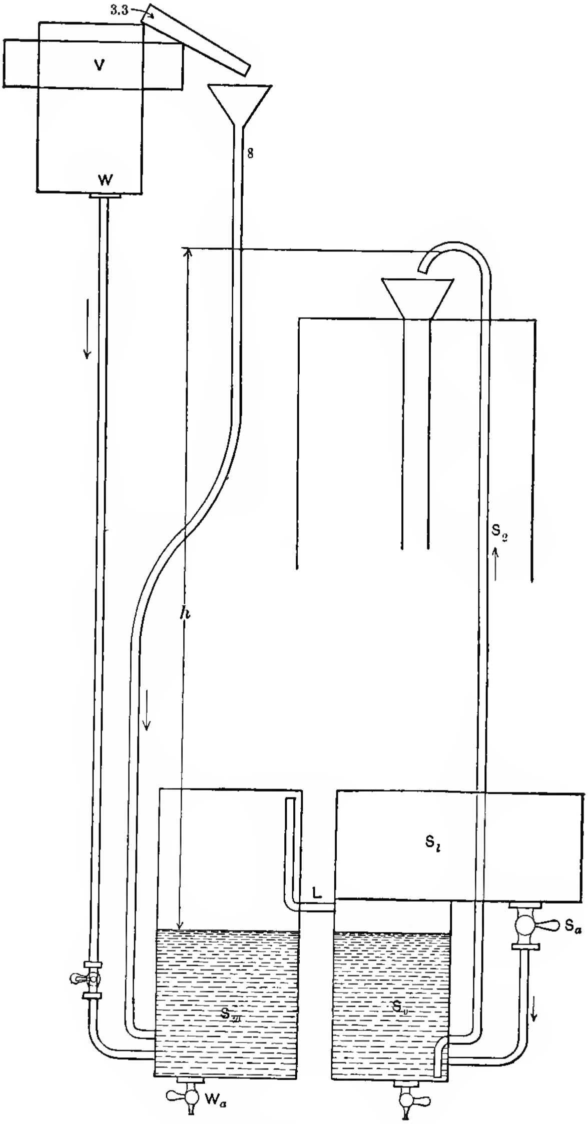


Fig. 39

pare the soda-solution on the ground floor below, and then raise the latter up in the following manner (see Fig. 39).

The soda-solution, prepared in open vessels, will be admitted into the closed vessel S_v by opening the cock S_a. After the closing of the cock S_a, as much water will be let down from the distributor *V*, shown with the deep bottom, into the somewhat larger closed vessel S^w alongside, so that the air, which is in both vessels (entering from another opening), causes a pressure corresponding to the column of water *h*.

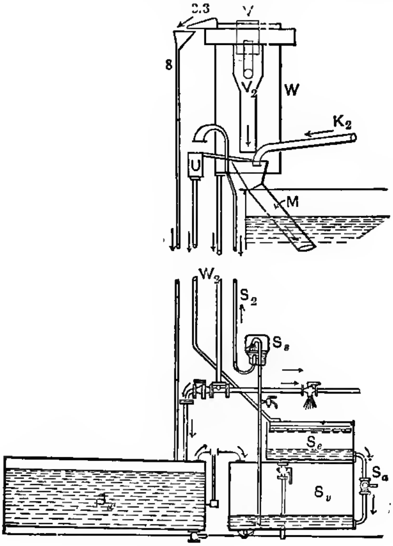


FIG. 40.

If now the water, flowing over the distributor at 3, 3, flows into the air-vessel S_w through the pipe 8, a similar quantity of soda-solution will flow out through the pipe S_2.

In Figs. 40 and 41 are shown the necessary vessels for the distribution of the soda, and in Fig. 40 the air-chambers are separated from the lime-vessels; in Fig. 41 they are shown in connection with the lime-vessels.

D. Preparation of the Charge of Caustic Soda and Lime-water.

If the raw water is to be treated with a mixture of caustic soda and lime-water, which is of advantage where great quantities of lime-water would have to be used, the soda-ash solution

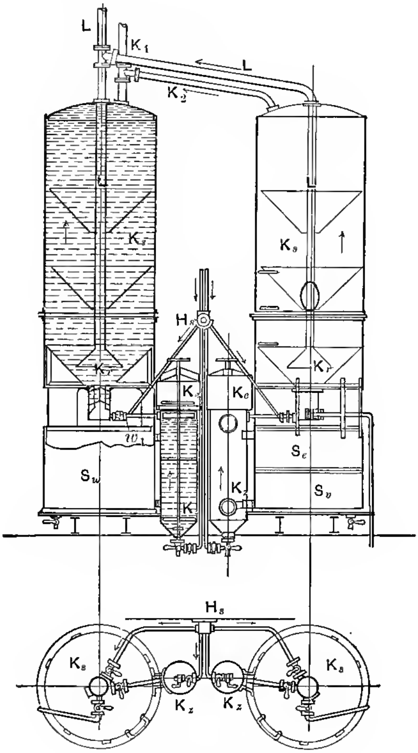


Fig. 41.

must be conveyed to the lowest part of the lime-vessel. It forms here caustic soda, and the rising water contains a mixture of caustic soda and lime-water, which may be used direct as reagent water.

But as the presence of caustic soda in lime-water makes the solubility of CaO more difficult, and the lime-water will thus be made less effective the more caustic soda there is contained in the water, moreover, as the control of the lime and the caustic soda-strength in the mixed water is not so easy as when the lime-water and the soda-solution can be tested by itself (each solution by itself),—we abstain from the higher soda requirements (above 5°) first used by Von Stingl, who favored these, with good results, but still causing too difficult methods of preparation, and treat with separate solutions,—lime-water and soda-ash. The only advantage the addition of soda-ash to the lime-water has is that the clarification of the reagent water is better and more continuous, because a great deal of precipitate is formed by the mixing together of lime-water and soda-ash.

E. Preparation of Caustic Soda.

Treatment with caustic soda alone can only be used with such waters as may be grouped together under Case 2.

As commercial caustic soda is too dear and not pure, containing as it does some soda-ash, the caustic soda is prepared by bringing together at intervals the lime- and soda-ash in the desired proportions in two troughs, and with the solution-water in a heated condition.

If the causticization (as the conversion of soda-ash to caustic soda is called) takes place in a cold condition, the precipitate created as $CaCO_3$ will be extraordinarily voluminous. It would cause, therefore, the loss of a great quantity of soda-ash in the refuse.

If there is no possibility of previously heating the solution, commercial caustic soda must be used.

The test of the purity of this caustic soda as to soda-ash is made by pouring hydrochloric acid in a test sample of the caustic soda. If the liquid effervesces, some more lime must still be added.

Theoretically we may take 1/2 kg. CaO to 1 kg. of 100% soda-ash to produce caustic soda; but as the CaO is cheap, and as the lime is depended on to produce completely causticized soda, take 1 kg. burnt lime to make 4 liters of thick dissolved lime per 1 kg. of calcined or ammonia soda.

With water, which must be treated with caustic soda, two tanks for the soda solution are necessary to maintain a continuous discharge without interruption, and to maintain the strength of reagents.

F. Mixing of the Reagents with the Raw Water and Clarification of the Treated Water.

In order to be able to accurately carry on the treatment of water, we will consider more closely the preceding methods.

If, for example, the reagents necessary for its purification are well mixed with the raw water in a glass liter-flask, large flakes will be seen to form after the first incipient cloudiness.

The liquid in which these flakes float becomes opalescent. But by degrees these liquids clear themselves, and this clarification takes place first at the top surface.

The flakes sink lower all the time; at the same time the opalescence of the liquid becomes constantly less, finally disappears, and it becomes pellucid, while the precipitate adheres to the sides.

After an hour the incipient loose and flaky precipitate sinks together into the smallest space and covers the bottom in thin layers, which are low or small, depending on the amount of loose magnesia precipitate it contains.

The precipitate has now become crystalline; it has the smallest volume and has acquired the greatest specific weight. The liquid standing above it is now entirely clear, but has not yet reached the greatest softness desired.

The above occurs during the first hour after the addition of the reagents in a cold condition.

The alkalinity of the pure water likewise diminishes during the first hour. Both these facts are an evidence that, after the first precipitation of material, an after-reaction occurs, and that therefore the purifying process must be given a certain time, in order that the precipitation may be made the most complete.

The so-called rapid filters therefore may take out the heavy precipitate very well, but cannot prevent the incrustation of the pipes which carry away the treated and filtered water. In order to prevent this occurrence, a period of more than three hours is absolutely necessary.

The clearing tank of the water-purifying apparatus should therefore be designed with the greatest possible volume.

Also the shape of the tank has an influence on the rapidity of clarification of the water being treated.

In a narrow and high tank, the early voluminous precipitate cannot settle down as easily as in a shallow and broad settling tank, because the water particles already purified cannot so easily make way for those coming down from above.

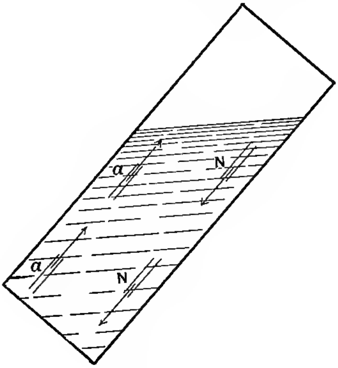


FIG. 42.

This is best shown if we incline a settling vessel. There then occurs a downward current of precipitate (*N*) and a rising current of the purer water (*a*), causing an easier separation of the one from the other.

This behavior of treated water has led to the employment of movable plates obliquely placed.

A very considerable shortening of the time of clarification will often be effected by warming the raw water, by having the water fall over plates in a closed chamber, and by passing live or exhaust steam through it.

This procedure is only possible where the water requirements are small.

At most railway water-stations, the quantity of water to be purified is usually so great, and the amount of steam required for the purpose so great, that it cannot be heated before treatment.

One important modification of the clearing process occurs when the additions to the raw water are made under a high head of water, as the water pressure brings the particles nearer each other and thereby aids the chemical action.

On this account the use of high clearing-tanks, in which the mixing of the reagents with the raw water takes place at the bottom, is of advantage as compared with shallow and broad settling-tanks.

It will be further noted that waters which contain large quantities of bicarbonate of calcium and calcium compounds clear quicker than those which contain bicarbonate of magnesia or gypsum.

This is shown by the following consideration:

In a water of 10° hardness (caused by bicarbonate of calcium) .356 grams of simple carbonate of calcium per liter is precipitated by purification with caustic lime.

From a water of 10° hardness (produced by bicarbonate of magnesia), on the contrary, only .178 gram of simple carbonate of calcium per liter is precipitated by caustic lime. The plain magnesia carbonate remains partly soluble in water. This can only be removed by a corresponding excess of caustic lime, and comes down as a precipitate composed of .356 gram calcium carbonate and .103 gram magnesium hydroxide. But, as in water purification the addition of such an excess would make the water too alkaline and often impossible for use, we cannot cause a quick clarification in this manner.

From a water of 10° hardness (produced by gypsum), like a water containing bicarbonate of magnesia which was not treated with an excess of caustic lime, barely .178 gram of plain calcium carbonate falls as a precipitate.

In the customary treatment of water, the strength of the water in bicarbonate of calcium also makes a difference in the clarification.

Very hard waters, if they are treated with the proper reagents, clarify themselves much quicker than waters which, while containing some scale-forming matter, are yet relatively soft.

The clearing of waters under 14° hardness will always be prolonged. But it may be hastened, if the mixture of the raw water with the chemicals is carried through old precipitate, or if an artificial precipitate such as pulverized chalk or pulverized brick dust is introduced. The latter method was suggested by Engineer Breyer.

It is very advantageous to have the additions to the raw water brought together at one spot, so that all precipitants, the lime-water with the soda and the precipitates which both these cause in the raw water and the caustic soda formed, meet at one place, because, by doing this, the quantity of precipitate will be increased and the strata of precipitate be thicker, and this will form a natural filter for the treated water passing through.

The best possible mixing of the reagents with the raw water also causes an acceleration of the clarification. It is therefore recommended that stirring devices be used.

The preference, of course, will be given to stirring devices operated by manual labor or by machinery, and this includes the stirring devices previously described as being used for the preparation of the lime-water.

It is also very important for the clarification of the water that it be completely at rest during the clarification, or that it rise with the least possible velocity.

While, as mentioned, in many cases the first precipitate falls very rapidly (about .2 mm. per second), the fine precipitate formed later sinks to the bottom very slowly (about .01 mm. per second). Therefore, in case a continuous stream of water is to flow through the water-purifying apparatus, the velocity of the rising current should not exceed .2 mm. per second.

In this case only a small amount of precipitate will be carried on to the filter, and the latter will be effective for long periods without back-washing.

In water-purifying plants, which work on the settling principle, the mixing of the raw water with the reagents will take place alternately in two or more large tanks.

In water-purifying plants which are continuously operated, the water must either be allowed to flow very slowly through the vessels, or the water must be alternately passed through two chambers, in such a manner that, as it flows through, it will be alternately relatively at rest in each space.

Clarification takes place in a shorter time in still water. This time can be still further shortened by the insertion of oblique plates on which the particles of precipitates sink down through shorter distances.

The reversal of the current of water from motion to rest may be effected by the tilting-vessel already described.

A reversal of the inlet water by hand into two clearing-vessels has been already effected by the use of the tilting-vessel of Von Richling.

If the open oblique plates mentioned are so placed that the distance in which the precipitates are formed is in a definite ratio to the velocity with which the precipitates fall; if the falling precipitates can avoid the rising pure water, as is possible, according to Figs. 30, 42, whether the water in both systems of oblique plates is at rest or in motion; if the dimensions of the vessels are great enough; if the water is previously heated, or if it is mixed with the reagents under pressure; and if the water is not too soft,—then, if a uniform and properly measured quantity of reagents are added, the best purification may be expected.

G. The Mixing-place and Clarification Arrangement.

Into the funnel-shaped wide-mouthed mixing-place *M* enters the inflowing raw water through the pipe w_1, as well as the chemical water pumped through k_1; the chemical reaction begins immediately.

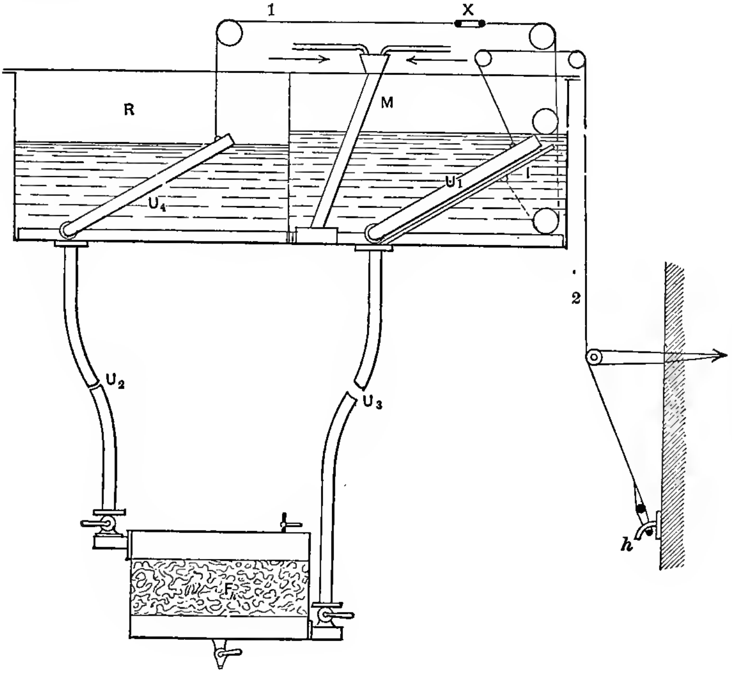


FIG. 43.

The calcium and magnesium compounds and the carbonate of ferrous oxide will precipitate as calcium carbonate, magnesium hydroxide, and iron oxyhydrate.

By rising in the broad reservoir *M* the water clears itself, but is not yet so it can be used. Now the previously purified water entirely clear is admitted to the reservoir *R*, and a decanting device, U_1, U_4, is used, so that the contents of both reservoirs may be used for the delivery of pure water.

This consists of a decanting-pipe, U_1, taking the water out of compartment M near the upper surface, which rests on the hinged guide L, which is provided with two floats, a descending pipe U_3, a wood-fibre filter F, a rising pipe U_2 connecting with the decanting-pipe U_4 in the reservoir B.

The end of the guide, provided with floats, on which the drain pipe U_1 rests, and the drain-pipe U_4, are connected with a chain, 1, over rollers, which is always stretched by the weight of the pipe U_4.

Both decanting-pipes will therefore be governed by the pair of floats shown in M and rise and fall with these. The mouth of the decanting-pipe in R lays about 140 mm. below the surface of the water in reservoir M, therefore the water taken out of R can always be replaced again from M. This head is also sufficient to let out the entire quantity of water through the pipe, guide, and filter composing the decanting device.

The head is regulated by means of turn-buckle X, otherwise it is unchangeable and depends on the water taken. By pumping out reservoir M to the bottom, no precipitate will enter the decanting-pipe U_1, because when this water is drawn out the open end of the pipes comes above the water while the floats remain in it.

This draining out is effected by a wire rope 2 with a ring which hangs from a fixed hook h.

If now the rising water rises so high that the guide with the floats reaches and raises the elevated decanting-pipe, the roller rope 2 slackens, the ring swings itself free from the hook h, the decanting-pipe now rests freely on the guide L, and the overflow into reservoir R begins without further help.

After each withdrawal of water from R the water taken out is replaced by the stream flowing from M, the surface of the water remains the same until both reservoirs are empty, when the water must be pumped in again.

The filter F is a cylindrical-shaped wood-fiber filter. The entrance of the water to be clarified takes place below the layers of wood fiber, while the discharge occurs from the top.

If sand-filters are used the difference in head between the surface of the water in M and the outlet opening of the pipe U_4 must be correspondingly greater.

A pure clear water of 4° hardness was obtained in a small experimental apparatus, in which the distance between the oblique glass plates used from each other was 10 mm., in which the velocity of passing was .2 mm. per second, the quantity of liquid passing through was 20 liters per hour, and the area through which it passed 100 sq. cm., while the same water in a Berenger apparatus when the discharge was clear could only be brought to a softness of 11° to 12°.

When we tried to get a greater softness, 7° hardness for example, the water was not clear.

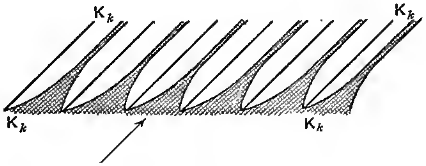


Fig. 44.

In this small apparatus the thickening of the precipitate seemed to have especially influenced the clarification.

It was apparent that the water rising between the oblique plates, which was wholly turbid below the entrance to the plates, was changed by its entrance to the space between the latter, because the distinctly turbid middle layers and the entirely clear side layers flowed in opposite directions in the neighborhood of the plates.

After flowing through the oblique spaces a longer time, the entire quantity of water passing through became turbid. After a short period of quietness, which was accomplished intermittently by a tilting-vessel operating every 25 minutes, the water in the oblique plates was entirely clear, and it appeared as if the thickening of the precipitate was influenced by the small distance of the oblique plates from one another, and that the attraction of the plates had played an important rôle.

The precipitates were easily washed out by the draining off of a sufficient quantity of water.

Perhaps a way is pointed out by this experiment by which we can accomplish a complete clarification of turbid liquids without filter material. In this case we would lay the oblique plates very near one another, and have a very convenient washable and indestructible filter.

But for water-purifying plants such a filter would be too large and too costly.

CHAPTER IX.

REVIEW OF THE DEVELOPMENT OF WATER-PURIFYING PLANTS.

Before entering on the description of the more recent water-purifying plants, it is advantageous to take a look back over the development of water-purifying.

The first man who sought to purify water was an Englishman named Clark.

This celebrated English chemist in the year 1841 conceived the thought that water could be purified of its bicarbonates by the use of milk of lime.

But in most cases he could not obtain a satisfactory result, because the greater number of his waters also contained bicarbonate of magnesia, on which the milk of lime was effective only when in excess and then only partially.

Also by his treatment it was not possible to precipitate a water containing gypsum.

The investigations of de Haen, Nolden, and Bohlig which took place later, to free water by chemical means of its scale-forming matter, were only accompanied by a partial success, as the chemical additions did not correspond to the nature of the water.

The Austrian Hungarian State Railway Company gave every attention to water purification, as they used chemical preparations for making boiler-scale rotten before the year 1864; later, and, indeed, until the year 1864, the water exclusively for locomotives was previously heated by means of Schau'schen and Haswell's apparatus and since 1866 the method of L. Maderspach, chemist and chief engineer for the Imperial Government of the Austrian Hungarian State Railway Company in Orawicza, has been used at the steam-mill in Roman-Orawicza with satisfactory results.

The method of L. Maderspach for the purification of water consists of treating the warmed water with caustic lime (in the form of milk of lime) according to its temporary hardness, and with soda-ash according to its permanent hardness.

Maderspach caused the precipitation to take place in three reservoirs placed one above the other.

In the year 1872 he saw the advantage of filtering the water after his treatment, as he could then accomplish his purpose with one reservoir and greatly shorten the period of purification.

Berenger,* inspector of the Austrian Southern Railway Company, likewise recognized the advantage of filtration and used it in his first water-purifying plant in 1859 at the Modeling Station of the Southern Railway. For the treatment of the water he first used no soda, but only caustic lime and in the form of lime-water.

But later he, in company with the Austrian chemist Stingl, approached nearer to the question of water purification; in 1874 he made use of both caustic lime and caustic soda in dissolved form (Austrian patents of the 18th XI), and later in the year put their method in full operation, both theoretically and practically.

Since the year 1878 the methods of Berenger and Stingl † have been used by all railroads, and if the later water-purifying plants treat by means of lime-water and soda-ash instead of lime-water and caustic soda, as was used by Berenger and Stingl, still this does not change the importance of the method of treatment as given by Stingl, by which the water was treated according to its chemical characteristics with a clear solution of lime-water and caustic soda, relatively with caustic soda and soda-ash or with a solution of caustic soda alone, as in the end the soda-ash formed from the caustic soda and the carbonic acid of the bicarbonates always acted on the gypsum.

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* Jean Alexander Berenger, born Aug. 15, 1825, at Thain (Department of the Drôme), studied at the École Centrale in Paris, was from 1853–55 director of the Lead Works in Stolburg (Westphalia), 1855–57 manager of the Septem Machine Works at Marseilles, 1857–60 civil engineer in Paris; became engineer for the Southern Railway, May 1, 1860, and inspector of the Southern Railway on pension in 1880.

† Johann Stingl, born April 28, 1842, in Luck, near Carlsbad, in Bohemia, studied in the Vienna Polytechnic, where he was later instructor. From here he came to Czernowitz, and was then stationed in Bielitz with the title of Member of Council. He killed himself on Aug. 7, 1891.

Just as these chemical principles of Stingl's were the foundation for the chemical part of water purifying, so were Berenger and Stingl the pioneers in displacing the great settling-tanks of Clark with their deceanting treatment used with filters, which to-day in different forms is still that generally used.*

The first water-purifying plants of Stingl and Berenger were:

1869 in the Modling Station on the Southern Railway Company.
1872 " " Belvedere Gas Works in Vienna.
1873 " " Vienna Exposition.
1874 " " Florisdorf Jute Spinning Mill, the Voslau Yarn Spinning Mill, and Caslau Station of the Austrian Northwestern Railway Company.
1876 " " Vienna Station of the Austrian State Railway Company.
1877 " " " " " " Southern Railway Company.
1878 " " " " " " Austrian Northwestern Railway and the Grazer Iron Ware Factory.

The Southern Railway Company, the Imperial Railway Company, and the Austrian Northwestern Railway have greatly contributed to the development by building the first Berenger and Stingl apparatus.

Besides this the Austrian Northwestern Railway with their own staff have completely or newly erected types of water-purifying plants in Caslau (1886), Zellerndorf (1887), and Josefstadt * (1891), which by the avoidance of special features make possible the purification of water in the simplest and cheapest way.

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* Weichmachen, Reinigen, and Klaren fur jeden Industriellen Zweck nach dem System J. A. Berenger and J. Stingl, Wien, 1878, Im Selbstverlage der Verfasser.

The Austrian Northwestern Railway has given to their staff every facility and convenience for the special study of water analysis.

As a consequence every one interested in the results obtained is able, by means of a simple technical treatment of the water † with an hour's investigation, to calculate from the simple formulas of Kalmann, professor in the higher technical schools in Bielitz, the amounts of reagents to add for purification.‡

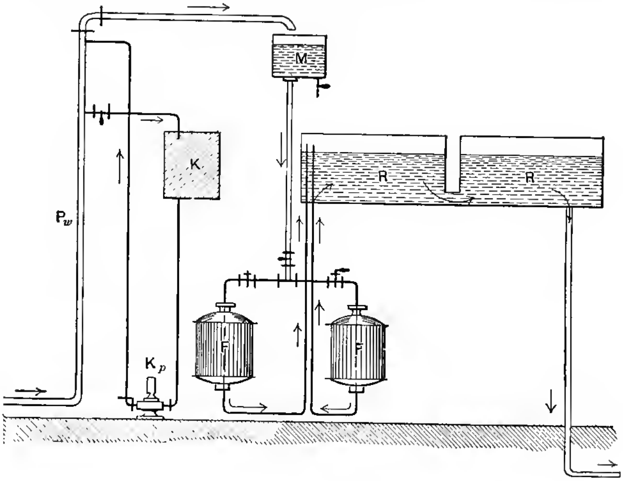

FIG. 45.

In the accompanying sketches is shown one series of water-purifying plants installed by the Austrian Railway, and the improvement accomplished is evident.

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* Encyclopedia of Railways, Dr. V. Roll, "Feed-water," Vol. VI, Figs. 1581, 1582, 1583.

† Organ fur die Fortschritte des Eisenbahnwesens, 1893. Uber die Untersuchung und das Weichmachen des Kesselspeisewassers von Edm. Wehrenfennig, inspector of the Austrian Northwestern Railway.

‡ Eisenbahntechnik der Gegenwart., Vol. II.

Fig. 45 shows the first water-purifying plant built according to Berenger's system at Modling Station of the Southern Railway, in which lime-water was injected by a pump into the ascending pipe and the treated water was passed through a collecting tank and simple pressure-filter into pure-water reservoir.

The pressure-filters consist of (see Fig. 46) a closed cylindrical vessel with the two convex heads as shown, and filled with filtering material below which is placed a sieve.

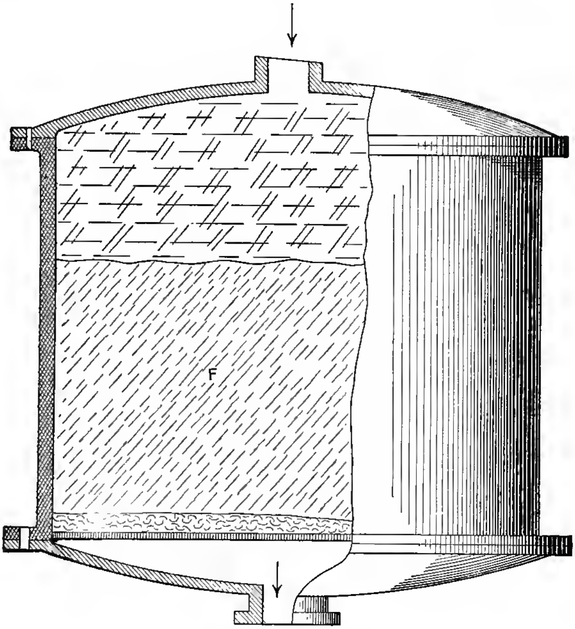


Fig. 46.

The filtering material consists of shavings alone or else two-thirds of the latter and one-third coke.

Fig. 47 shows the later improved water-purifying plant built by the Austrian Northwestern Railway after Berenger's system at the Caslau Station.

While at first the lime-water was injected into the pipe under pressure and passed through a mixing-chamber and two pressure-filters to the reservoir, in more recent times in order to dispense with tedious manipulation the pressure-filters were removed and the decanting method used.

In this the turbid mixed liquids are first carried to the bottom of a high reservoir where they are cleared by rising slowly and then overflow into a second reservoir as pure water.

Up to 1886 the treatment was made with lime-water only, and since that date the water has been treated with a mixture of lime-water and caustic soda.

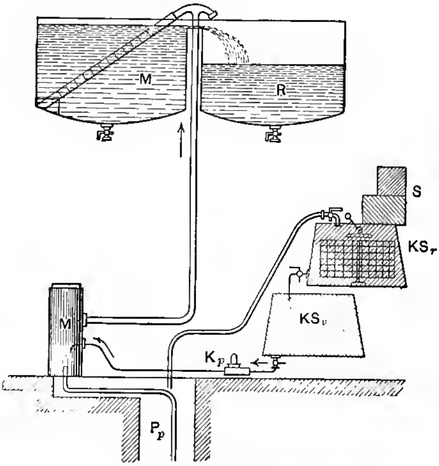


Fig. 47.

The lime-water is produced with the help of a stirring apparatus.

The first plant of the Austrian State Railway Company at the Vienna Station in the year 1874 (Figs. 48 and 49) was equipped with pressure-filters similar to those at Modling and Caslau Stations which were placed on the floor of the machine house.

With this arrangement the raw water was first conveyed by a means of a pump located outside of the house into a large air-chamber equipped with a pressure-gauge from which it passed to the point of mixture with the liquid reagents.

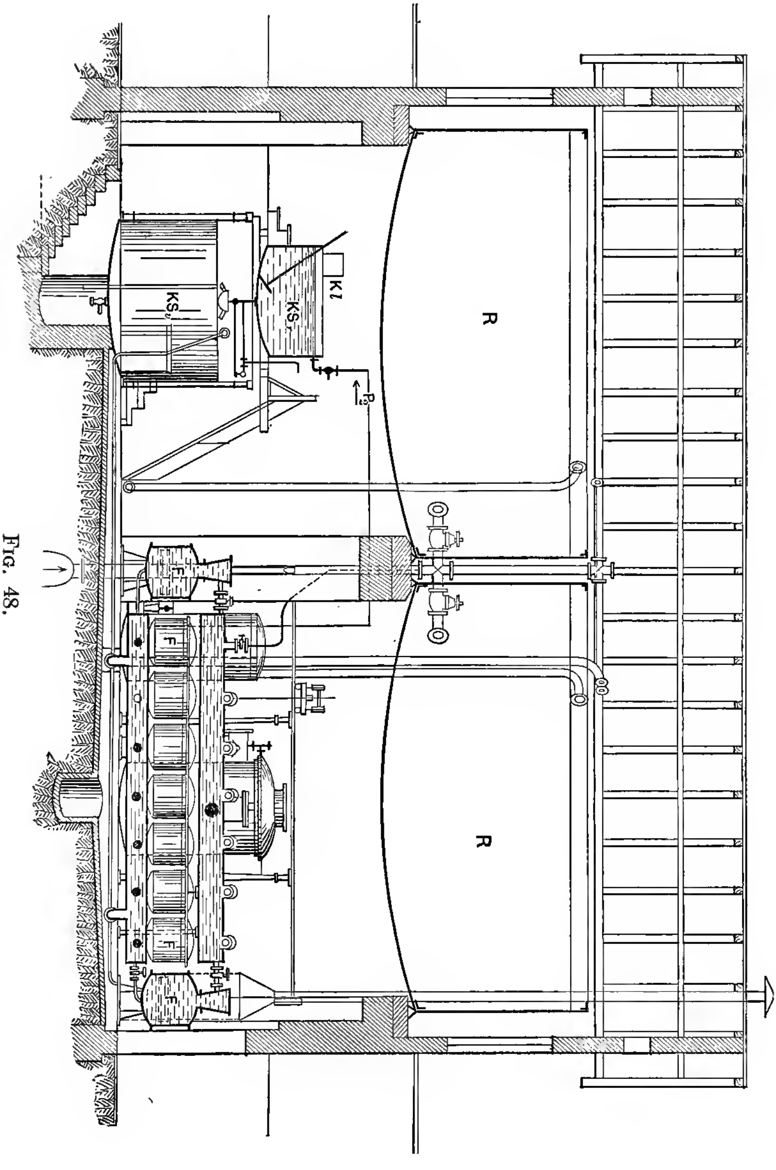


FIG. 48.

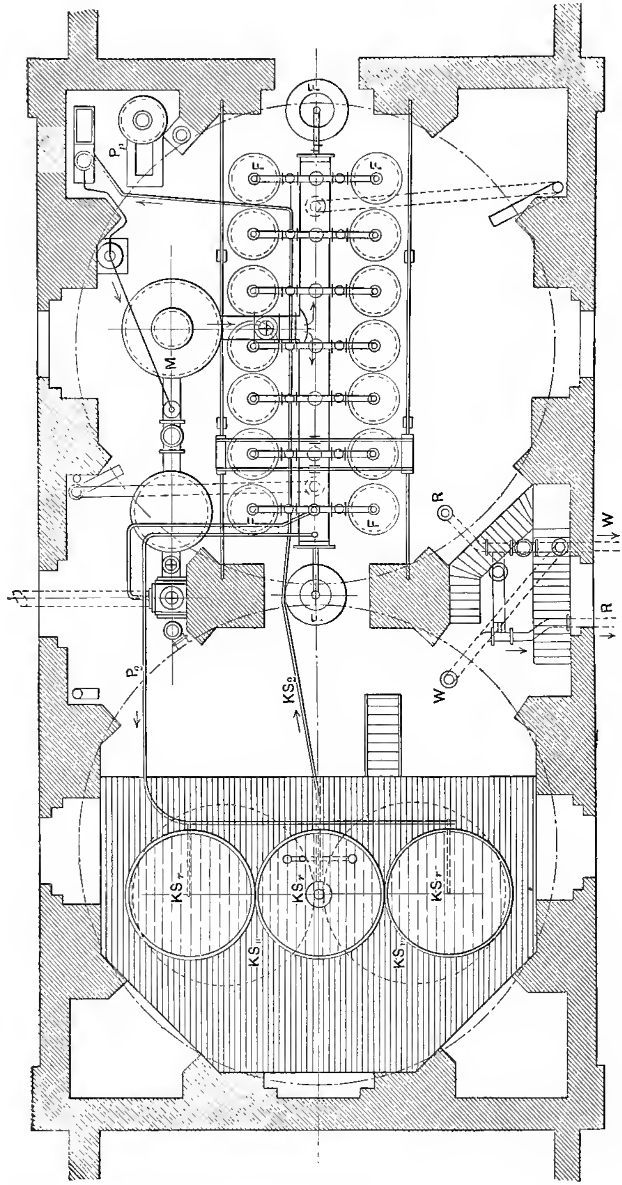


FIG. 49.

The mixed water now entered a roomy mixing-vessel and, through a wide collecting-pipe placed on both sides of the former, was brought to the pressure-filters. From these the filtered water rose (through a second collecting-pipe) to the pure-water reservoir.

The reagent waters were prepared without machine agitated apparatus in reservoirs placed alongside, and consisted of a mixture of lime-water and caustic soda.

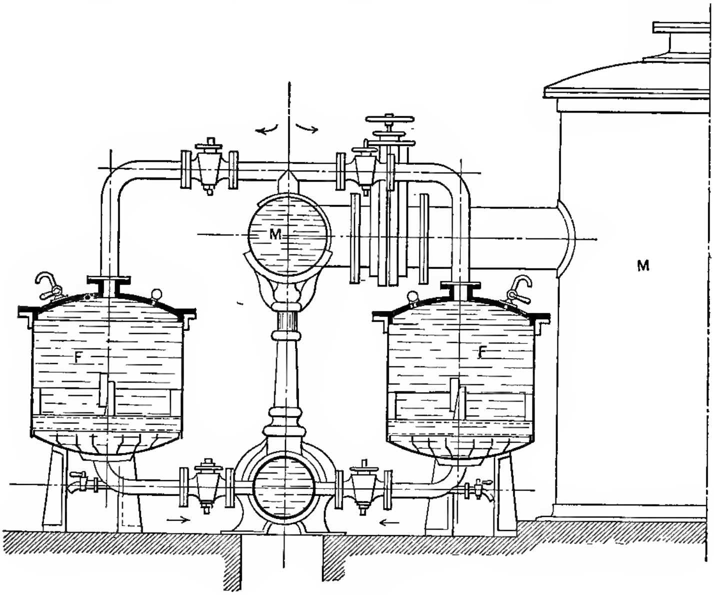


FIG. 50.

The pressure-filters were constructed after the Austrian patent of Berenger of the year 1873 with two sieve bottoms with wooden rings placed thereon. Between the sieves and above the same the filtering material was placed, consisting of wood shavings and coke; the rings of wood were for the purpose of preventing the passage of unfiltered water between the sides and the screens; the coke served to hold back the chips which balled together.

A complete renewal of the filtering material lasted from four to five months; the top layers had to be washed out every two or three days.

In the years of 1877 and 1878 Berenger built a continuously working apparatus after the decanting system patented on Oct. 7, 1876.

But while the Southern Railway Company built an apparatus according to this system at their station in 1877, as in his former apparatus the manipulation still took place with pressure-filters on the floor of the machine house. Berenger recommended to the Austrian Northwestern Railway an apparatus in which the reagents required by the water were added by means of pumps by a proportional inflow from tanks placed high up.

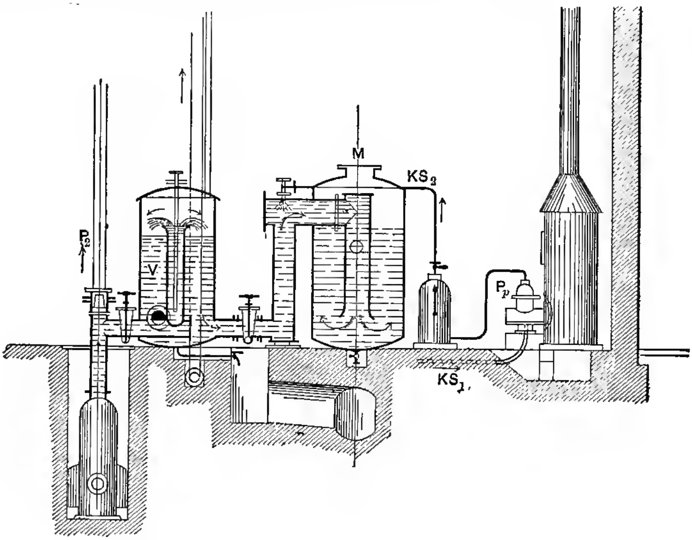


FIG. 51.

Such a purifying apparatus of Berenger and Stingl is still used by Brand and Lhuellier in Brunn, in which the clarification takes place by repeatedly drawing out and finally filtering the water, and is shown in Fig. 52. It consists of the reservoir for the additions, lime-water, and caustic soda, caustic soda alone, or caustic soda and soda-ash solution; *c* is the vessel for the discharge of the soda-ash, or for the preparation of caustic soda, *d* is the pressure-regulator, from which the descending reagent water flows uniformly. This is accomplished by a float, which regulates the outlet opening according to the position of the water; *e* is the mixing-tank in which the raw water mixes with the additions. The mixed water flows through a central pipe to the bottom of the high mixing-tank *e*, rises in the surrounding space, and flows in this manner up and down through the clearing vessels *f* and *g* into the filters *h* and *i*, filled with wood fiber.

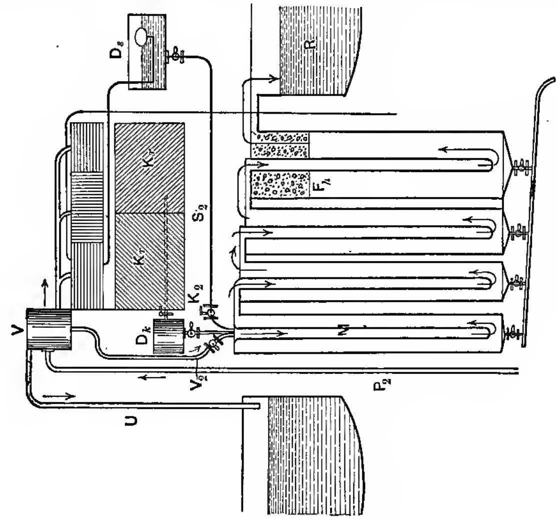
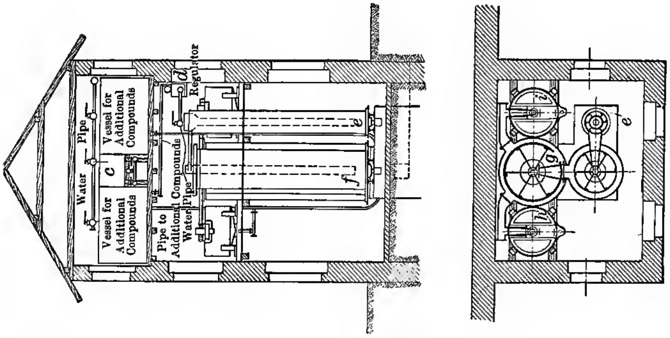


FIG. 53.



Water
Pipe
Vessel for Additional Compounds
c
Vessel for Additional Compounds
d
Regulator
Compounds
Pipe to Additional Water Pipe
e
f
i
g
e
h

FIG. 52.

In the mixing-cylinder *e* the precipitate rises in large flakes, in the clearing vessels it rises as finer bodies, and in *g* as very fine particles. These attach themselves to the wood fiber in the filtering-tanks, which must be washed from time to time. The greater part of the precipitate remains behind in the bottom of the tanks as a consequence of the change of direction and must be frequently drained out.

In Fig. 53 the Berenger apparatus of this type is shown as installed by the Austrian Northwestern Railway.

Instead of operating this apparatus, as was the custom at the time, by admitting the caustic soda to the lime-water tank and then using the mixture produced thus for treatment, which caused incomplete causticization of the soda on account of the strength of the lime-water, and very injuriously affected the results of purifying, the author since 1885 has allowed the lime-water and the caustic soda solution to flow into the raw water separately, and since doing so has obtained a continuously uniform character of pure water.

The necessity for an efficient automatic lime-saturator, which should not require to be set to work by hand stirring, caused the construction bureau of the machinery department of the Austrian Northwestern Railway in the year 1877, which at that time was under the management of Central Inspector Herr Ant. Elbel, to undertake the question through Engineer Siegmeth, in such a manner as to automatically deliver the lime-water to the contemplated water-purifying apparatus. For this purpose Herr Siegmeth filled a high glass with lime and added a corresponding quantity of water to the same from below. With slow filling the milky liquid in the lower part of this tube cleared itself, and the water at the overflow was found to be completely saturated and quite clear.

The plan of the water-purifying plant was worked out on the basis of this experiment, and is shown in Fig. 54. K_s is the lime-saturator, *M* is the clear reservoir, *R* is the pure-water delivery reservoir. It is to be regretted that this project was not carried out.

It is regrettable that the discovery of the continuous lime-saturator, which was first produced in Vienna, was first used in Belgium under the name of Dervaux, and only later in Austria and Germany. But unquestionably the priority of this construction, which since has made its way around the world, belongs to the Austrian engineers Elbel and Siegmeth.

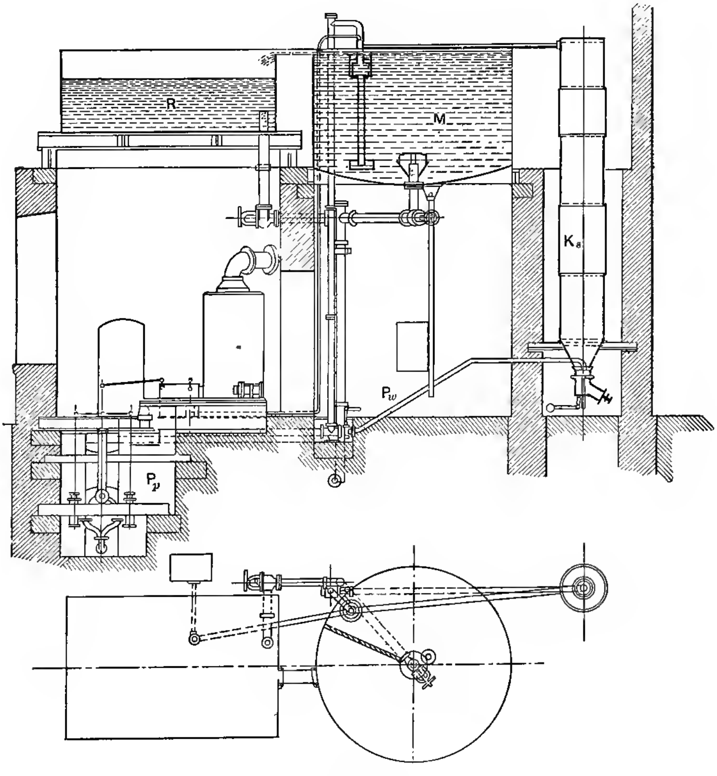


FIG. 54.

Fig. 55 shows the arrangement of a water-purifying plant according to the Dervaux system, which consists of a clearing vessel *M*, a measuring vessel *VS*, placed above it for the distribution of the raw water and the preparation of the soda-solution, and a lime-saturator K_s.

The raw water is pumped into the raw-water reservoir *W*, placed over the purifying apparatus, and from this is conveyed to the latter. The pure water is collected in a reservoir *R*. The great drawback is that with this plan a very expensive tower-shaped building must be erected and that the preparation with lime and soda-ash necessitates the lifting of them to a considerable height, prevented a quick introduction of this purifying apparatus for the water-stations of the railroads; in spite of this in a short time a series of these plants in different forms have been built by the manufacturers. Several of the latter are mentioned later on.

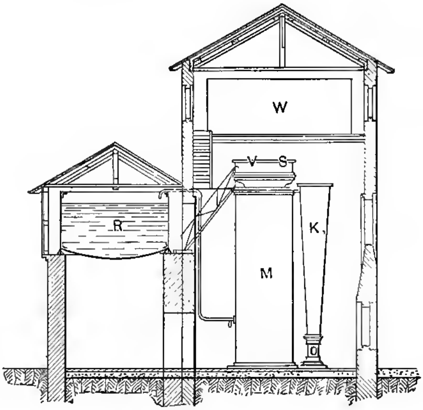


FIG. 55.

The purifying apparatus of Dervaux (Fig. 56) consists of a clearing-chamber *D* with cone-shaped plates placed one above the other and is either without a filter or with a wood-fiber filter as in Fig. 57*a*, or with a Reisert filter placed in the lower part as shown in Fig. 58.

Above the clearing-chamber *D* is placed the distributing vessel, from which the raw water, lime, and soda flow through the properly adjusted cocks, *P*, *V*, the siphon *N*, and the pipe *U*, and into the clearing-chamber *D* through the pipe *E*.

The water divides itself in the numerous clearing divisions *GG*, and flows out finally through the collecting-pipe *A*, while the precipitate deposited on the plates slips down and sinks to the bottom, from which it is drained out.

The preparation of lime-water takes place in the funnel-shaped lime-saturator *S*, to which the water is admitted through

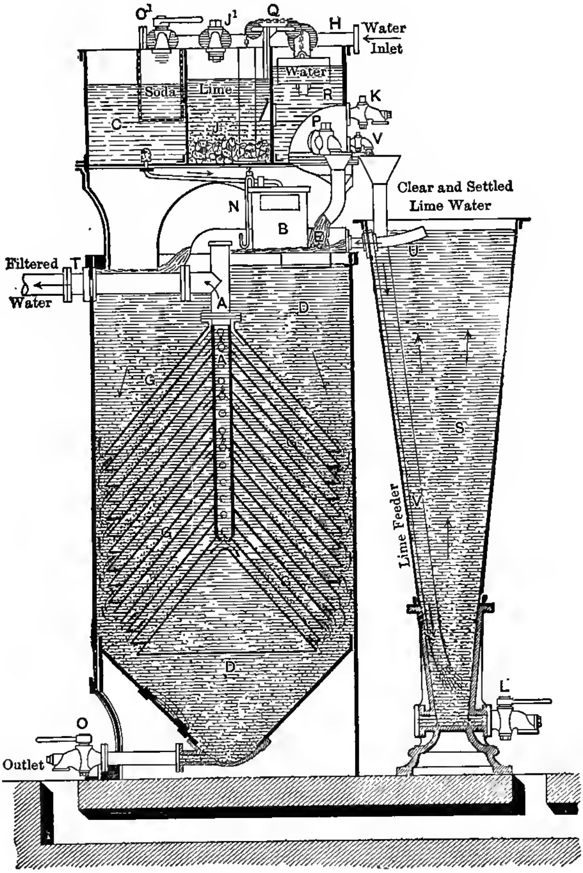


FIG. 56.

the cock *V*, and the milk of lime flows in at intervals from the space *J*, in which there is a solution of lime.

The soda prepared in the space *C* flows from here into the vessel *B*, the inlet being controlled by a float, as shown, and is discharged from this by means of the siphon *N* into the pipe *E*. The siphon and the float in the vessel *R* are so united by a chain

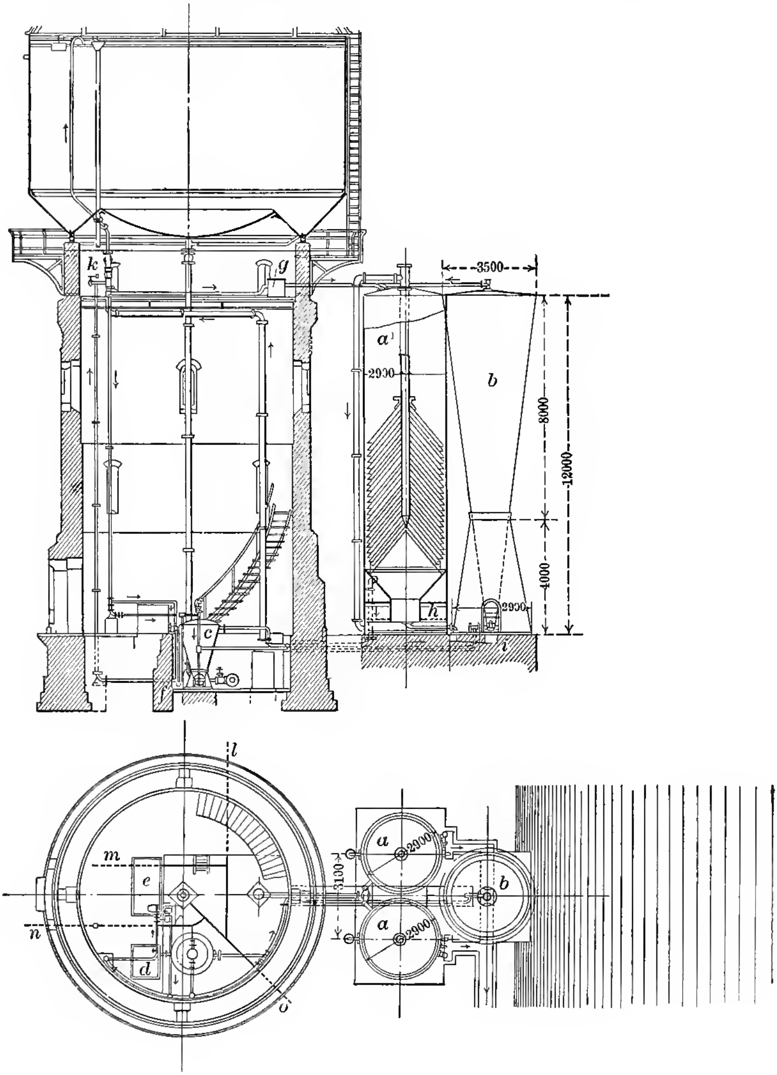


FIG. 57.

over rollers that, by the sinking of the latter, the siphon-pipe is raised; the outflow of soda-solution is correspondingly diminished, and is completely stopped if the chamber *R* is emptied.

A partial clarification takes place in the funnel-shaped enclosure, but a Reisert filter is better.

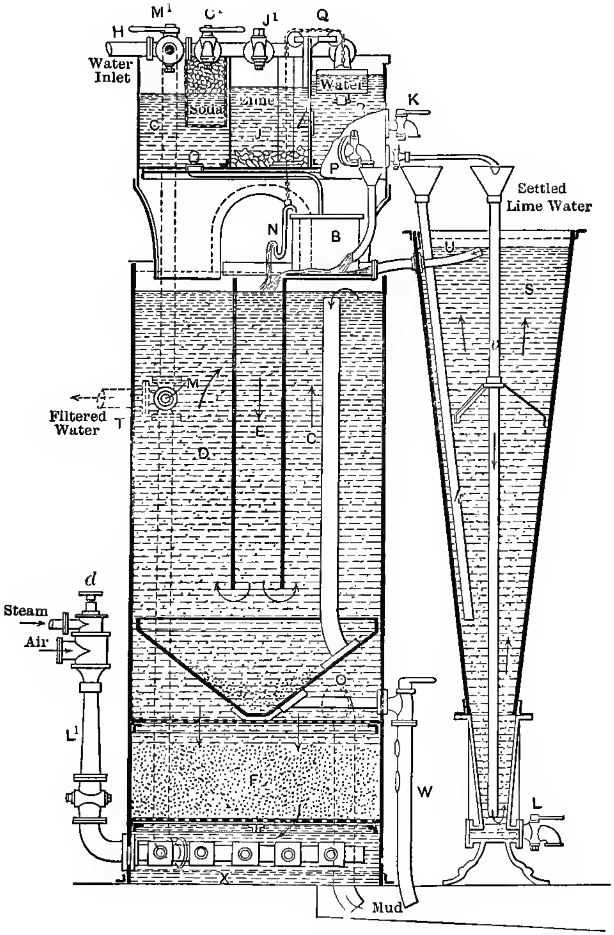


FIG. 58

The water-purifying apparatus of Desrumeaux (Fig. 59) is provided with spiral-shaped clearing-plates (*N*) (*J*), not only in the purifying-chamber but also in the lime-saturator.

The precipitate will be removed from the space *P* by means of the valve *S*, and out of the lime-tank through the valve *U*.

The lime will be placed in the space *R* and be led through the sieve and the central pipe to the chamber below. The raw water passing through the valve *D* is conveyed by *H* into the hollow rotating stirrer and through this to the bottom, where it saturates itself as it rises in consequence of the agitation of the stirring-arms which are fastened to the hollow spindle, stills itself as it passes through the radially placed partitions and flows over the top.

The agitation is accomplished through a water-wheel, put in motion by all the entering water. A float *B* operates an outlet valve which is placed in the soda vessel *C*.

After its passage through the wood-fiber filter *O*, the water flows through the outlet *T*.

The apparatus of Humboldt (Fig. 60) for lime consists of oblique plates and a wood-fiber filter, then the raw-water reservoir *A*, two reagent vessels *B*, in which lime and soda are mixed and out of which the reagent water flows from the clear upper surface by means of decanting-pipes.

The vessel *C* contains three divisions. To the left enters the reagent water, to the right the raw water.

The quantities are regulated by valves. The float and outlet valves maintain a constant water level. In the middle space of the vessel *C* the raw water is mixed with the reagent water, and the mixture then passes in a long zigzag course through the space *D* and the wood-fiber filter to the discharge.

The apparatus must be extremely large, or else the velocity of flow will be too high.

The apparatus of Gaillet & Huet has oblique plates, similar to those of Desrumeaux, only they are not laid out as continuous spiral surfaces; besides, they consist of numerous tables, whereby the whole area of the clearing-chamber is used to better advantage.

With the apparatus of Reinecken (Fig. 61) the slowest possible velocity of the rising current is possible, and a good

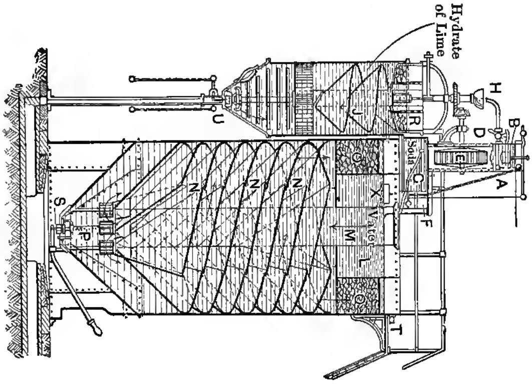

Hydrate of Lime
H
B
D
E
A
R
J
U
Soda
C
X
F
Water
M
L
N
N
N
N
S
P
T

FIG. 59.

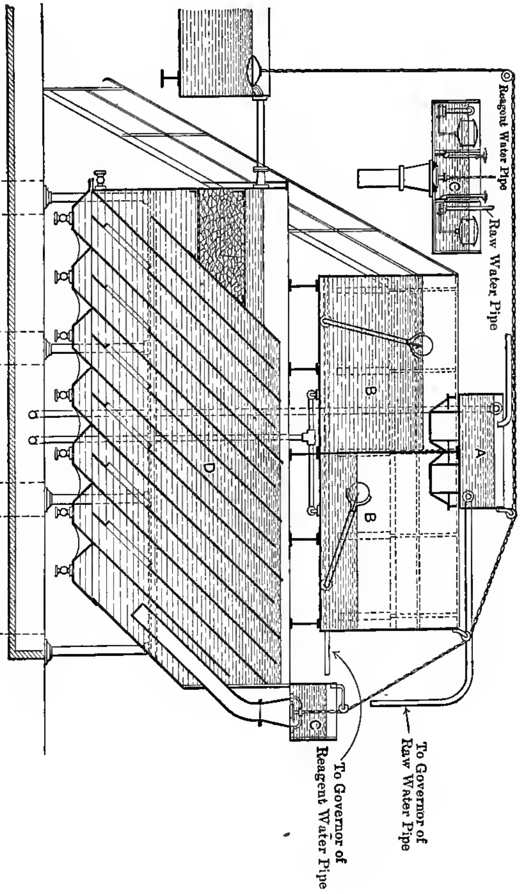

Reagent Water Pipe
C
Raw Water Pipe
B
A
B
D
C
To Governor of Raw Water Pipe
To Governor of Reagent Water Pipe

FIG. 60.

precipitation takes place in consequence. On account of their large size they require no filter.

The apparatus of Reichling (Figs. 62, 63) consists of two clearing-tanks with a heater, which may be dispensed with if the boiler-water is admitted into the purifying apparatus.

Reichling uses the Rossel system of soda regeneration, which consists of introducing soda-ash to the warmed raw water, which, by its action on the bicarbonate compounds of lime and magnesia, is changed into bicarbonate of soda, by which the carbonate of lime and carbonate of magnesia are precipitated (page 41).

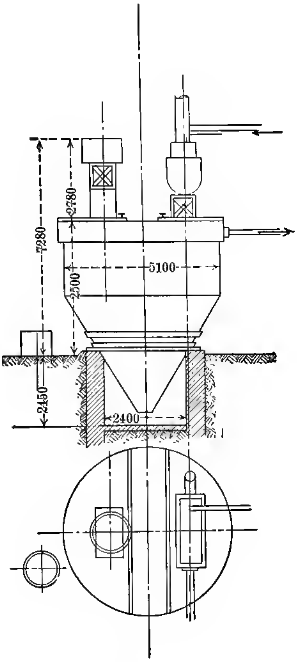


Fig. 61.

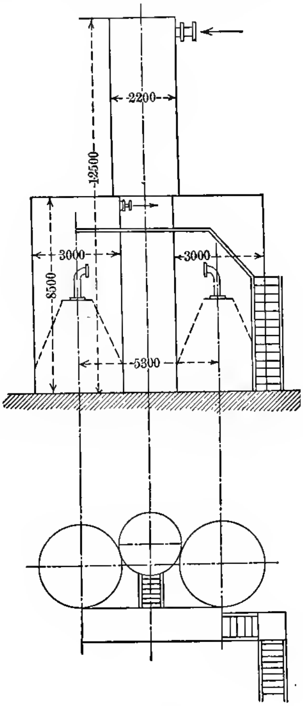


Fig. 62.

Through heating, the bicarbonate of soda again changes to the plain carbonate of soda (soda-ash). New soda-ash is only

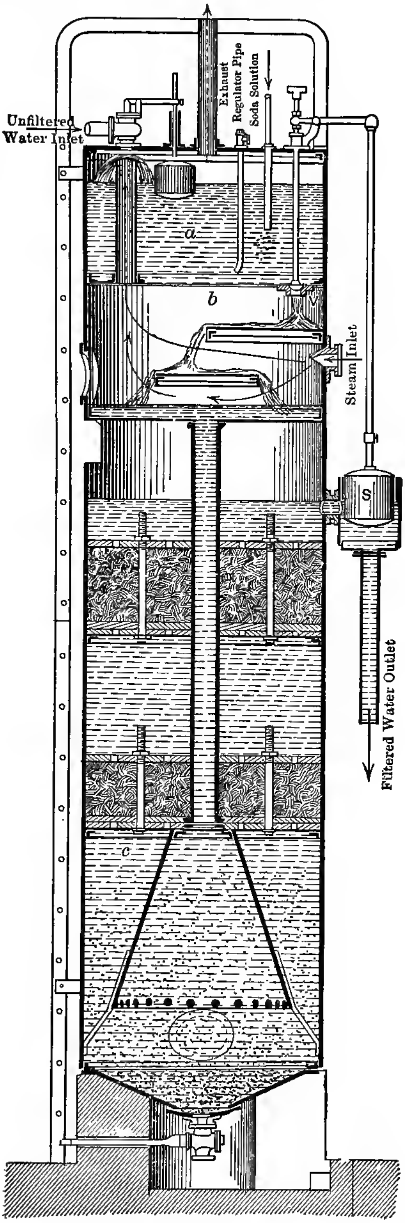

Unfiltered Water Inlet
Exhaust
Regulator Pipe
Soda Solution
a
b
V
Steam Inlet
S
Filtered Water Outlet
c

FIG. 63.

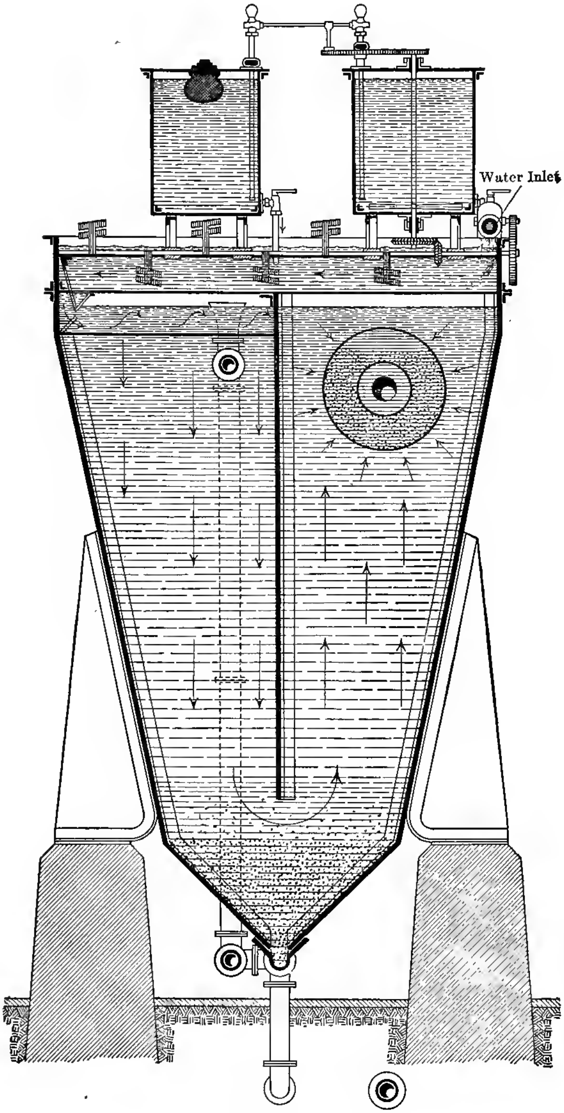


Fig. 64.

required by the presence of sulphate of lime, chloride of lime, and magnesia.

In the apparatus of the City Purifying Company General of Wiesbaden (Fig. 64) the clearing-chamber is divided into two chambers by a middle partition not quite reaching the bottom. Above both these chambers is a shallow mixing-pipe in which the raw water and the reagent liquids are mixed by means of a stirring cylinder. The mixture now flows into one of the two chambers, then downwards, allowing the precipitated material

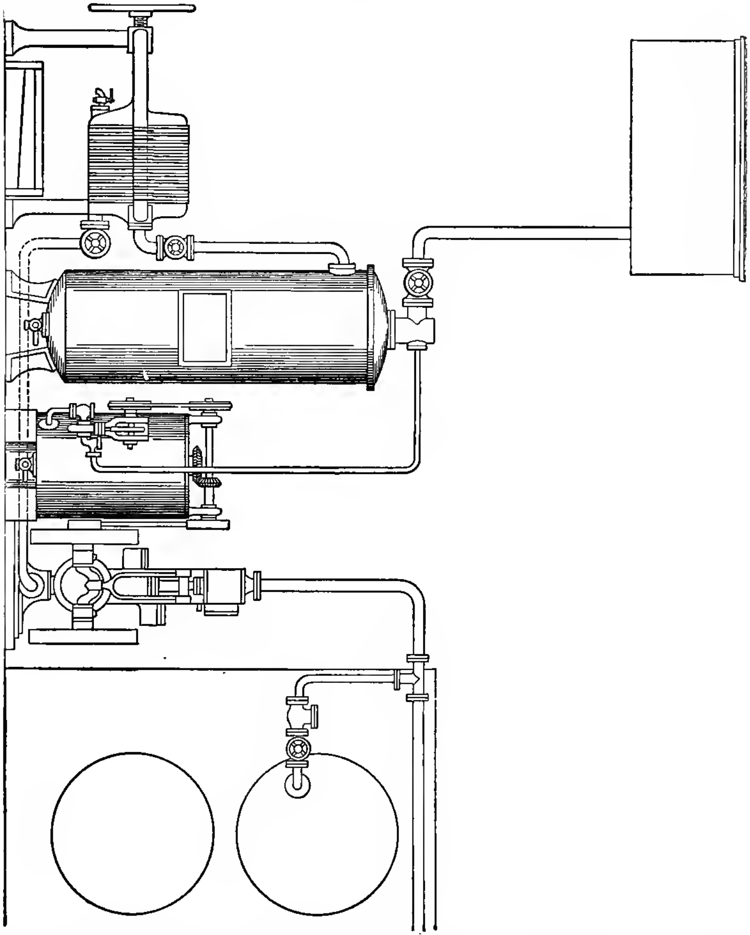


Fig. 65

to settle to the bottom, and rises gradually, clearing itself in the second chamber. The water thus cleared then flows out through a Kröhnke filter.

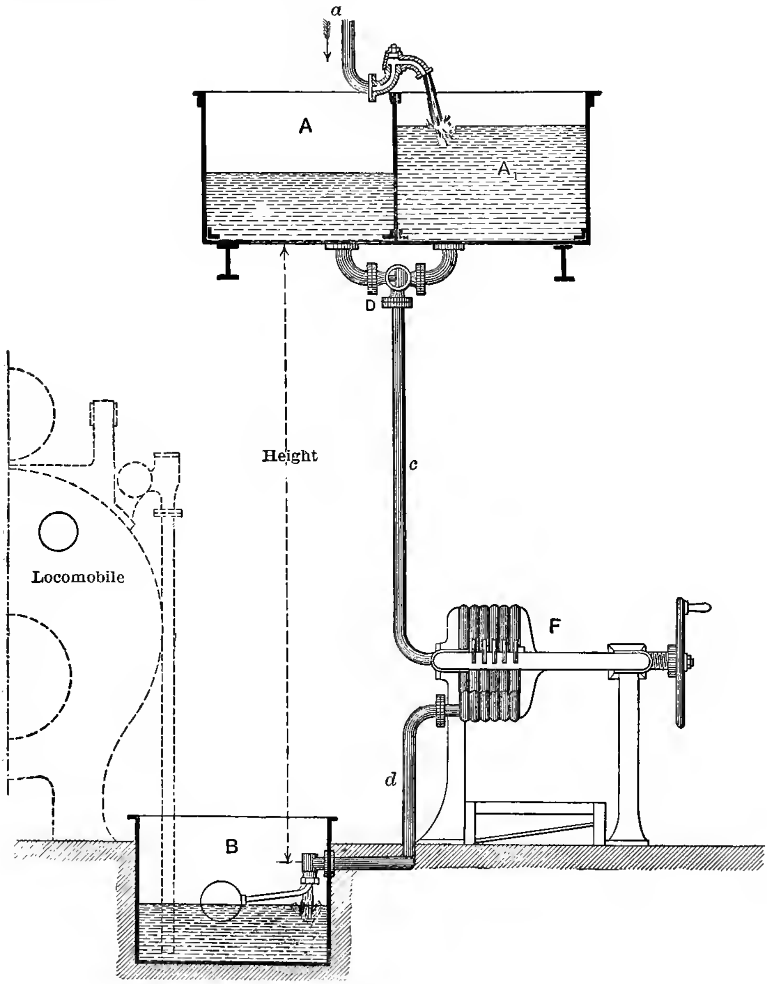


Fig. 66.

The reagent chamber is placed above the clearing-chamber. The distribution of the amounts of water is effected by valves.

Besides these water-purifying plants, there are a great number of newer constructions being developed one after the other, varying little in construction, in order to avoid the patented construction of Dervaux (the priority of which belongs to Elbel and Siegmeth), but in all of which, with the exception of the apparatus shown in Figs. 65, 66, the chemicals must be lifted to a height above the clearing-chamber. The arrangement, according to Dehne's system, permits the preparation of the reagents on the ground level.

But this system requires a pump and frequent handling for the removal of the precipitate from the filter-presses.

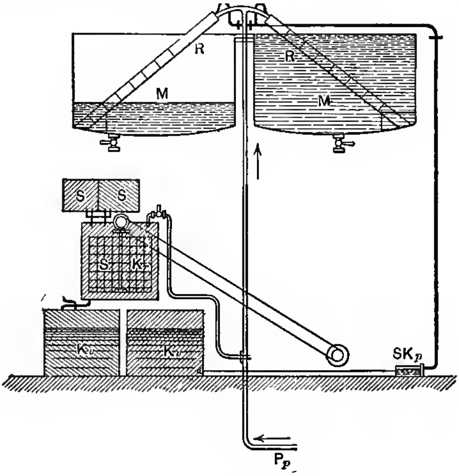


Fig. 67.

Purifying plants of this type are placed in the pressure line.

The inconvenience of the preparation of the chemicals at a height above the reservoir, and the great expense of such an apparatus, caused the Austrian Northwestern Railway Co., in the year 1886, to build a water-purifying apparatus at one of their stations, in which the manipulation was possible from machine-room underneath the reservoirs, and only cost $720.00. This arrangement is shown in Fig. 67.

Before 1886 the lime-water was stirred by hand, since 1886 by means of a stirring device driven by a steam-engine, and the soda-ash added directly to the same for mixing. The causticization was by these means made complete. The clearing of the water was effected, but always on the settling system.

A separate pump forced the reagent liquid to the place of mixture.

The clarification of the treated water took place alternately in each of the high reservoirs.

But on account of the great and greater demand for pure water, the purifying plant after several years was no longer sufficient, because the water alternately entering the two reservoirs for clarification had not sufficient time for clearing.

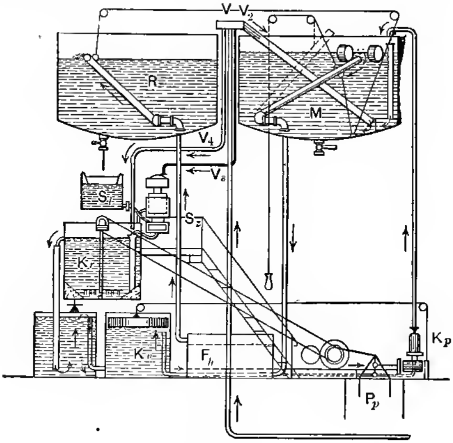


FIG. 68.

Therefore, in 1898, the apparatus shown in Fig. 68 was produced, which made it possible to produce twice the quantity of pure water delivered without increasing the space taken up.

In this it was managed that the two reservoirs were united with each other through a decanting apparatus and filter; the water mixed with reagents pumped into one reservoir was drawn out from near the top surface (because it was already very pure there), and led into the second reservoir through a filter; from here it is led to the outlet.

The lower ends of the decanting apparatus in both reservoirs * are used as decanting-pipes, are connected by a chain over rollers, and maintain a constant head between the upper surface of the mixed-water reservoir and the outlet mouth of the decanting-pipe in the pure-water reservoir.

On account of these connected pipes the filter cannot be washed to pieces by a sudden lowering of the surface of the water in the pure-water reservoir.

The water distribution, instead of taking place by means of outlet-valves which are hard to regulate, is effected by means of a circular weir, in which the overflowing water is divided by partitions inserted in the annular space, according to the result of the analysis and the calculated quantities (see page 88).

The raw water flows direct through the submerged pipe into the mixing-chamber, the raw water needed for preparation of the lime-water to the lime-stirring chamber, and the third part is regulated by a float apparatus, so that as much of the soda-solution flows out of the soda-chamber to the lime-chamber as water flows in (see page 110).

Finally the reagent water pump delivers as much of the reagent liquid which has been prepared as will correspond to the position of the by-pass valve of the reagent pump, which is governed by a float in the reagent tank.

From the foregoing it is apparent that it is possible to equip an average water-station with a water-purifying apparatus, exclusive of the buildings, at small cost.

At a station of the Southern North German Junction Line was built in 1891 a water-purifying apparatus (see Fig. 69), where on account of the raw water containing the proper amounts of carbonates and sulphates the purification could be accomplished with advantage by using caustic soda alone.

It was therefore possible to have an especially simple installation, and the latter consisted of only a small collecting-chamber

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* Page 123.

for all the raw water and of two small caustic soda reservoirs with pressure-regulators, and the water reservoirs which were on hand at the time.

The proportional admission of caustic soda to the raw water is accomplished, in the first place, by means of a peculiar connection of two connected valves which maintain the ratio of the inflowing proportions at all times, according to the changing demands for water.

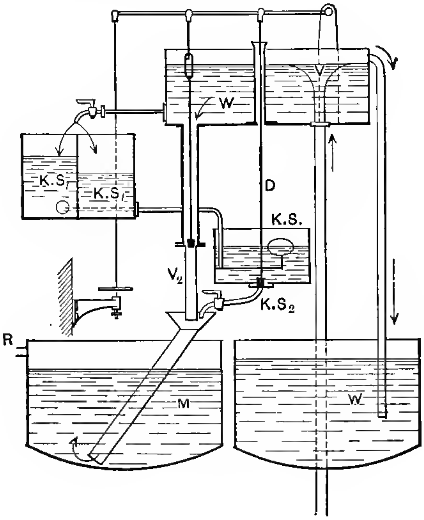

Fig. 69.

The clarification takes place in the reservoirs.

The preparation of the reagent liquids on the floor of the machine house would necessitate a small elevation of the latter to the mixing place and cause a loss of some of the simplicity.

This water-purifying plant which was calculated for 2 c.m. per hour, and was only to purify water for the shifting engines, was no longer sufficient after several years.

The capacity of the former was increased to 10 c.m. per hour, so the caustic soda had to be added in quantity corresponding to the water raised by the pump, and allowed to mix well in the two tanks *M, M* (see Fig. 70), and then so distributed by means of a divided weir in the chamber *Vm,* so that only 1/6 of the total water clarified itself in each of the six tanks present holding 5 c.m. In these tanks, which at the top held wood fiber through which the water passed to the collecting-tank *B*, there would be a very small velocity of the rising current, so the water was almost clear when it entered the wood fiber and passed to the collecting reservoir clear.*

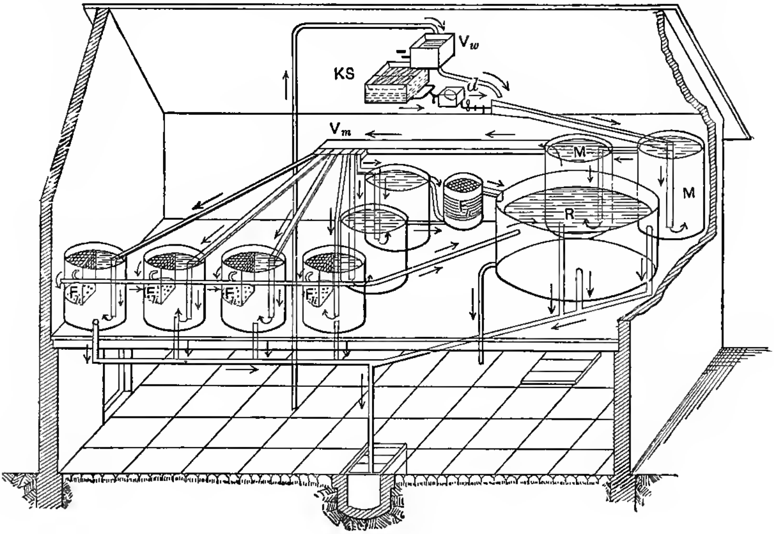

FIG. 70.

An apparatus having a capacity of 7 c.m. is shown in Fig. 71. The raw water is divided by a circular weir. One portion passes through the pipe *a* to the mixing-chamber M_1, another portion divides itself into a current flowing through the pipe D_1 to the bottom of the lime discharge *S* and into a portion, which is conveyed by means of the funnel *T* and pipe to the plunger moving up and down, which regularly feeds the lime into the funnel from below. In the lower portion of the lime-chamber the raw water is freed of its

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* This apparatus is no longer used, as raw water was since obtained which needed no purification.

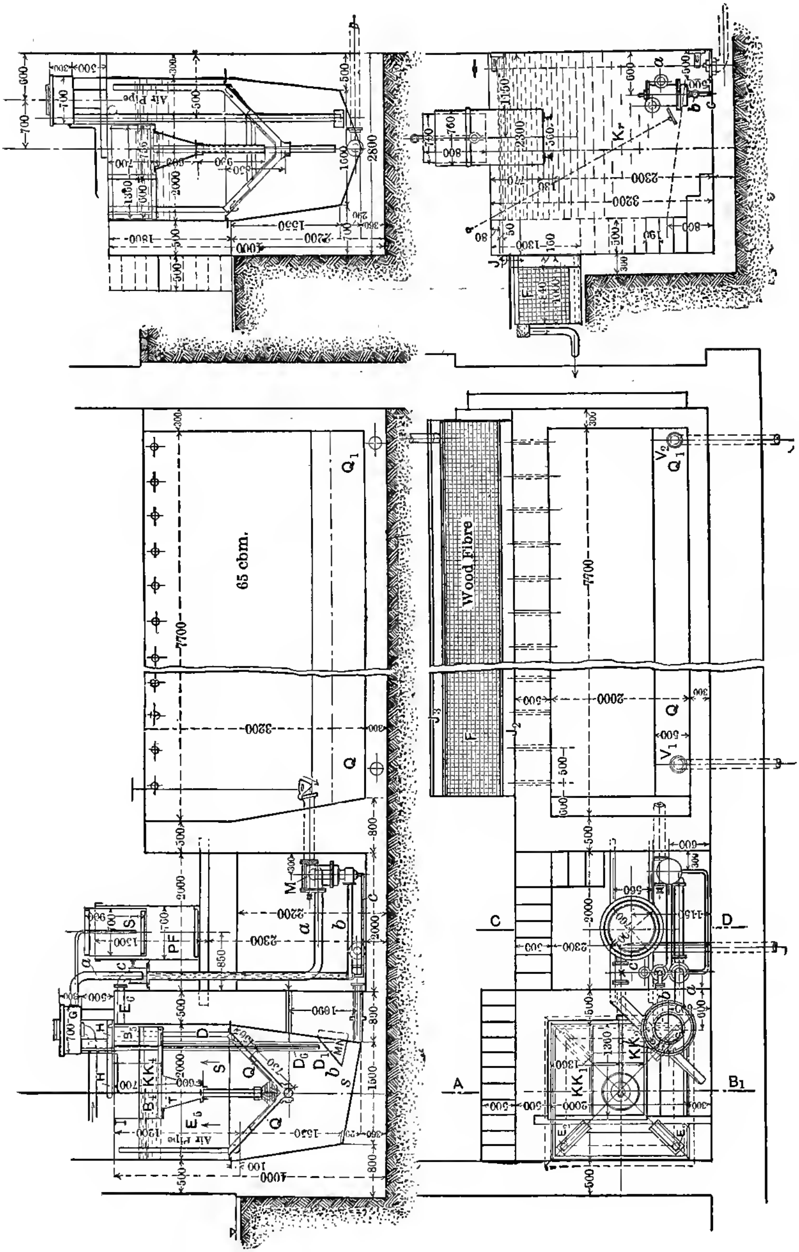
65 cbm.
Wood Fibre
Air Pipe
7700
3200
2200
2300
2000
1550
4000
1800
2800
1600
Q
Q₁
V₁
V₂
F
M
S
S₁
PF
G
H
KK₁
Kr
E₆
D₆
D₁
A
B₁
C
D
a
b
c

FIG. 71.

carbonates, then passes through the pipe E_2 into the stirring-chamber, where it loses the lime, and flows free from precipitates through the pipe b to the mixing-chamber.

A third part flows to the floating displacement S_1, PF, and forces out as much soda-solution from the lower chamber PF to the mixing-chamber through the pipe c as water flows in.

From the mixing-chamber the water enters a large concrete reservoir, in this it rises through the pipe J, arranged along the side wall, and after rising very slowly on account of the great area of the reservoir flows away clear through a wood-fiber filter.

The results of the analysis and the calculations pertaining thereto are as follows:

Bound	Co_2	125.2	milligrams per liter	$a=15.93$	lime	degrees
Calcium	CaO	170.5	" " "	$b=17.05$	"	"
Magnesia	MgO	118.1	" " "	16.53	"	"

Total hardness $=\text{CaO}+\text{MgO}=c=33.58°$, and according to the equations on pages 198 and 199

$$\begin{aligned} 2a-b&=31.86-17.05=14.81° \\ c-a&=33.58-15.93=17.65° \\ &\overline{32.46°} \end{aligned}$$

If the lime-water therefore to be added to 1000 liters is x_0 liters then

$$32.46°\times 1000=120°\times x_0,\quad x_0=270.5 \text{ liters.}$$

If soda-ash of 94.64% strength is to be used $17.65\times 2=35.3$; .353 Kg is to be used per 1000 liters, or if the soda-ash is dissolved in 12 times its quantity of water,

$$.353\times 12=4.24 \text{ liters per 1000 liters.}$$

To 1000 liters of the natural water must be added 270 liters of lime-water and 4.24 liters of soda-solution.

The principal divisions of the circular weir G are therefore to be arranged as 1000 : 270 : 4.24, therefore the circumference of the weir must be divided according to these proportions.

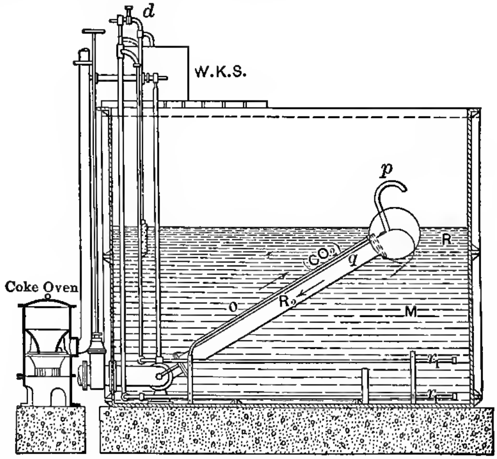

FIG. 72.

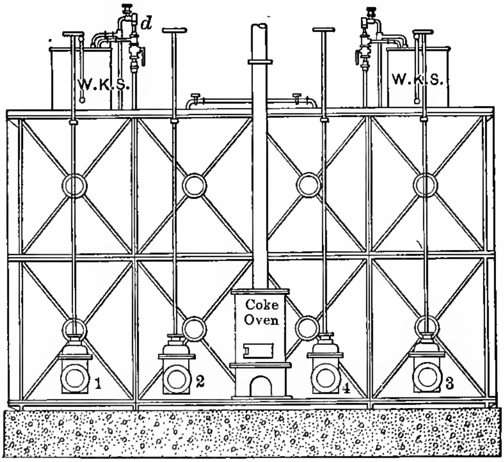

FIG. 73.

In the issue of October, 1899, of the "Bulletin de la Commission Internationale du Congres des Chemins de Fer," is described a water-purifying plant of Leonard Archbutt of Derby, chemist of the Midland Railway, in which the water is purified by means of the soda-ash lime-settling system and by carbonic acid, which is generated in a coke oven, and being forced into the purified water by a blast will make the final reaction harmless.

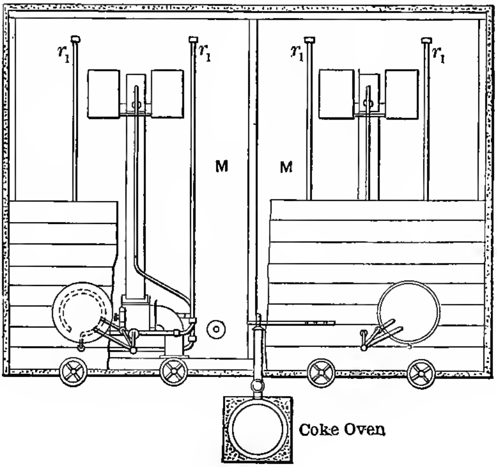

FIG. 74.

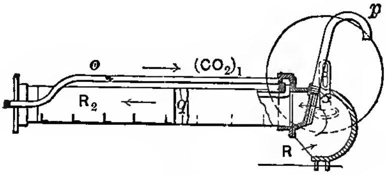

FIG. 75.

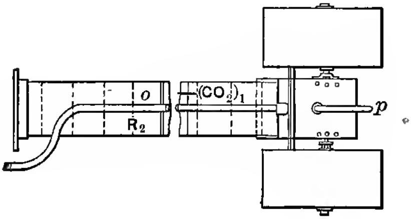

FIG. 76.

When the carbonic acid in a closed pipe is introduced into the water passing from the upper surface, it dissolves all the remaining fine precipitates formed. It will, therefore, prevent all incrustation in the pipes, injectors, and valves. (See Figs. 72 to 79.)

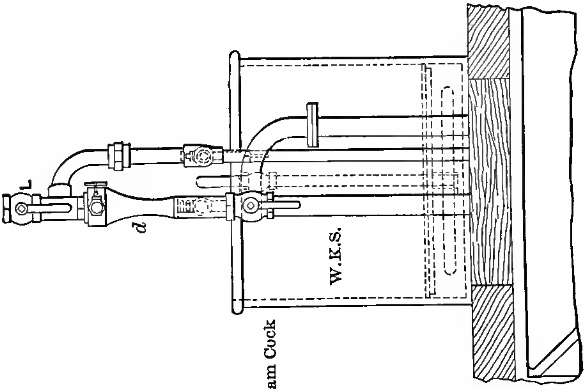

FIG. 78.

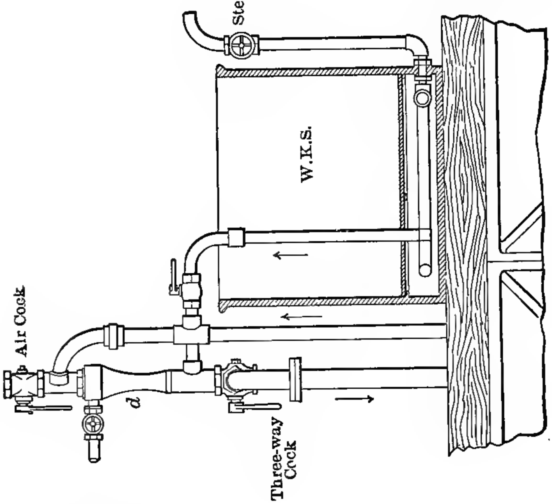

FIG. 77.

W, *K*, *S*, Prepared reagents.

d, Blast for introduction of CO_2 and for the rooting up of the precipitates by means of the perforated pipe r_1. The blast serves also for acidifying the reagents and for the mixing of the latter with the raw water.

o, Pipe for the introduction of CO_2 into the pure water.

p, Outlet-pipe for an excess of gas.

q, Outlet-pipe for pure water, whose fine precipitates have been dissolved by the CO_2.

The settling will be accelerated by the rooting up of the old precipitates by the air introduced. Because, by the newly found flakes adhering to the particles of precipitates which have already assumed the heavy crystalline form, the clarification will be hastened. This proceeding is always simpler than the addition of powdered chalk, brick-dust, or similar substances.

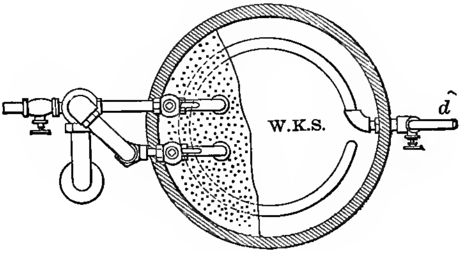

FIG. 79.

It is important to recognize, both from literature and in practice, that since the year 1892 a vital demand has been felt for the necessary knowledge to make water soft, and that since this period a great number of water-purifying arrangements have made their appearance. It may not be improper, therefore, to bespeak a certain interest for the work of the author which appeared in that year.

CHAPTER X.

CRITICAL EXAMINATION OF WATER-PURIFYING PLANTS.

If we would form an opinion as to which form of water-purifying plant should be chosen on the grounds of its suitableness, cheapness, and ease of operaton, we must consider the following facts:

Besides those designs which contain pumps, pulsometers, or conduits, we should consider next the hourly, daily, and, in small plants, the results shown for several days as to pure water for feeding locomotives, the raw water for washing out the boiler and tender, the type and manner of apportioning the liquids to the chambers by means of cocks, valves, or weirs, the time of passage of the water being purified, and of the lime-water through the clearing- and saturating-chambers, the velocity of the rising currents, the clearing height, the kind of filter, their area and filtering material, the period required for washing the filters, and the loss of water thereby occasioned, the relative loss of changing the filter-beds, and, where feasible, the approximate cost of the plant will be separated into the cost of the buildings required and the cost of the purifying apparatus.

As the uniformity of the character of the water to be used is of equal importance as the certainty of the operation, it must also be known; if the character of the raw water changes during the year and requires a change of precipitants, and what measures are to be employed to counteract the harmful influence of these changes of the character of the raw water on that of the pure water.

That the intelligence of the attendant plays an important rôle in water purification does not need to be raised here, as the omission to fill the chambers at the right time will produce an irregular result from the best apparatus.

It must be expressly noted if and how long the lime-water is completely saturated and flows out quite clear; if this should not be the case it is usually through a longer uninterrupted period of operation than that guaranteed by the builder of the apparatus; if the lime- and soda-solutions are always of equal strength (in spite of the removal of the effective material by the withdrawal of water); if the pure water always shows a uniform hardness, clearness, and alkalinity, and if foaming or priming of the boiler-water occurs and under what circumstances; if the injector of the locomotive becomes incrusted, and whether this is due to impure water or to water containing an excess of lime; if the tubes in the fire-box and stay-bolt heads show a salty exudation; if a noticeable formation of scale occurs in the boiler, and if scale formation occurs in the cocks. By first ascertaining the above facts the proper method of water purification will be apparent.

Also the calculation of the amounts of the additions, the products based on the analysis of small samples of water for water softening, the compensation of the latter for the character of water purified in large quantities, as well as the alkalinity of both which will be measured by 2/10 normal HCl, must all be considered.

The real reason for the priming of water will be better determined by an estimation of the standard of alkalinity of the pure water and of its clearness as well as its time of passage through the apparatus, as it frequently happens that this is ascribed to an excess of soda-ash where calculation shows not enough, and should be set down to other reasons (especially to the presence of magnesia carbonate). The filters can only produce a momentary clarification of the water, but cannot prevent a later reaction in the boiler.

For the technical investigation of water and calculation of the additions it is sufficient only to know the strength of the raw water in calcium, magnesia, and half-bound carbonic acid, yet the engineer will recognize at times from the analysis whether the water has characteristics which will lead to rusting of iron * or the corrosion of copper, which act so harmfully when working under the high steam pressure of boilers, but has less effect if the plates are covered with a partial protection of adherent scale.

If signs are present that the water attacks the iron or copper, we will ascertain where this attack occurs and to what extent, and not neglect to obtain a complete analysis of the raw water and the water in the boiler produced from the former giving the calcium, magnesia, iron, half-bound carbonic acid, sulphuric acid, chlorine, nitric acid, nitrous acid, ammonia, oxidizable organic matter, total residue, and residue after ignition.

From the comparison of the results of the analysis of the raw water and that found in the boiler, the boiler-water being taken shortly before washing out, a correct conclusion of the destroying properties of the water will be made known, and it will be determined by testing whether to make a reduction in the amount of water used, wash out frequently, or procure another water-supply from streams or deep wells.

Mechanisms suitable for the preparation of precipitants, the mixing of the solutions in proper proportions with the water, and the clarification of the treated water, must be simple and easily accessible. The chemical procedure must be so governed that the sedimentation will occur in the most complete manner possible, under the most favorable conditions, and the clarification must take place in the shortest possible time. This is effected by heating the entering water, where exhaust steam

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* Das Verhalten des Chlormagnesiums im Dampfkessel, von H. Ost. Chemiker Zèitung Cothen, Sept. 3, 1902.

Ueber Rostbildung im Lokomotive Kessel. Organ fur die Fortschritte des Eisenbahnwesens (S. Organ, 1891, 1892).

or other means of heating are available, especially with water containing magnesia.

If means of heating are not available this must be accomplished in other ways, which will aid in raising the standard of purification. Such means are:

1. Mixing together the precipitants with the raw water under a high pressure, or at least under a certain head of water.
2. Mixing together in a simple manner the definite amounts of precipitants determined from the examination of the water by means of devices, in which any small change of the proportions of the mixture required can be made by a change in the adjustment of the apparatus.
3. An intimate mixture of the precipitants with the raw water under pressure.
4. A long, continuous, and undisturbed leaving together of the exactly mixed liquids under pressure, in order to aid the crowding together of the separate particles.
5. Permitting the mixed water to remain a long time in the apparatus.

If the clearing-chamber is not large enough for the clarification to take place in it without special fittings or filters the clarification must be assisted by

6. A gradual and uniform rising of the mixed liquids in the clearing-chamber, whereby the large flakes of precipitate separate from the fine.
7. A repeated crowding together of the fine precipitates by which they will unite themselves in larger flakes and settle more easily.
8. Repeated inversion of the direction of motion, whereby the precipitate quickly sinks to the bottom, gradually rises again to the top, but at the moment of turning flows through the precipitate already settled and attaches itself to the latter. An alternate state of rest of the mixed water in two compartments of the

clearing-vessel, which are so filled with enclosures that the fine particles of precipitates can settle from the surfaces without being carried on with the following inflow of water, is of especial value. The duration of the state of rest and the distance the precipitates fall in these enclosures must stand in correct proportion to each other. The plates placed in the clearing-chamber must be so placed that all the rising particles of precipitate impinge on them.

9. Prevention of the carrying along of air by entering currents of liquids into the clearing-chamber and the liberation of the air carried along in the latter, or if air is used as a means of stirring securing a perfect liberation of the same from the water in order to prevent causing a turbidness later.

On the proper preparation of the reagents the following is to be said:

The lime-water should be made from freshly burned lime, or from dissolved lime protected against the entrance of carbonic acid by a layer of water, and the water so prepared that no flakes of precipitate are formed by its introduction to the lime. The former would surround the dissolved lime particles, retard their solution, and hinder their transmission.

The soda-solution is made without heating from commercial soda-ash and the purest water possible added together in the proper proportions. The handling of the apparatus as a whole should be convenient, and the cleansing of all parts should be easy, and should be carried out without great loss of a water.

Besides these technical criticisms of the value of water-purifying plant, an economical criticism must still be made, in which the cost of the plant will be compared with the amount of water it is designed to purify. If K indicates the cost of the plant in kroners (about 22 cents), and M the cubic decimeters of prepared water delivered, the value of the plant will be greater as $\frac{K}{M}$ is smaller.

For example, a plant with drain-pipes and decanting device would be more valuable than one without these devices, because with the first a considerably greater quantity of pure water is prepared for delivery and because further much less repairs are required.

In forming an opinion of the value of a water-purifying plant the way and manner of its operation has an important bearing.

This manipulation should be the simplest possible, the raising of material to the top should be avoided, and is only permissible at intervals.

The daily manipulation would take place from a platform or from a high landing.

The lime should not be dissolved each time in small lots, but should be taken from a lime-pit.

The soda-solution should only be prepared once a day at the most. The washing out of the filter should take place as seldom as possible, not only on account of the necessary waste of water, but also on account of the interruption to the operation.

The greater the dimensions of the clearing-chamber and the more complete the clarification of the water is before the filters have to handle it, the less often will the washing out of the filters be necessary.

Therefore, an ample size of the water-purifying plant has an advantageous influence both on the convenience of operating as well as on the results of the purification, and therefore the capacity of the clearing-chamber must not be designed too small.

CHAPTER XI.

STUDY CONCERNING THE INSTALLATION OF WATER-PURIFYING PLANTS.*

If it is determined, by means of a water analysis, that the water needs purifying, and no other chance of obtaining pure water is possible; if, further, the results of the analyses of water at different seasons, and taken at different states of the weather, do not show too great changes in the character of the water,—then we may begin the preparatory work toward the installation of a water-purifying plant.

The next question to arise is, whether the water may be purified cold or only in a heated condition, and whether the precipitation of the mechanical or chemical pollution contained in the water occurs quickly or slowly.

From these considerations we then determine what vessels are necessary, and what size we must give to the same.

The following two examples of softening tests will explain the preceding in a clearer manner:

The entering water for purification is turbid, has an odor and contains a soft, powder-like sediment.

One liter of water leaves behind 719 mg. on evaporation to dryness, which contains,—

In insoluble acids	5.2	mg.
Oxide of iron and alumina	3.6	"
Calcium (CaO)	151.6	"
Magnesia (MgO)	87.6	"
Carbonic acid (CO_2)	104.9	"
Sulphuric acid (SO_3)	214.8	"

Total hardness, 25.4 German degrees.

---

* Not every manufacturing process, where these processes may not have an odor nor be affected by alkalies, will permit the use of the condensed exhaust steam from treated water.

For softening per liter of water there is required 131.6 mg. calcium (CaO) and 174.3 mg. sodium hydrate (NaOH), corresponding to 135.1 mg. caustic soda (Na_2O).

For these analyses, and the results of the softening, the author thanks Chief Inspector Karel of Prague.

A. The Above Water Treated Without Heating.

1. After 3 hours. The filtered-treated water has an alkaline reaction; for the neutralization of 100 c.c. of the same, 2.28 c.c. 1/10 normal acid is necessary.

   One liter of water contains 33.2 mg. calcium (CaO) and 33.1 mg. magnesia (MgO), corresponding to 7.95 German degrees.
2. After 6 hours. Same water as above: 1.84 c.c. 1/10 normal acid were required for the neutralization of 100 c.c. of the water.

   One liter contained 32.2 mg. calcium and 24.0 mg. magnesia, corresponding to 6.58 German degrees of hardness.
3. After 12 hours. Same water as above: 1.70 c.c. 1/10 normal acid were required for the neutralization of 100 c.c. of the water.

   One liter contained 27.6 mg. calcium and 24.4 mg. magnesia, corresponding to 6.17 German degrees of hardness.

   From the above it is evident that approximately the best results of purification are obtained in 6 hours

B. The Previous Water Treated with Heating.

Before the addition of the reagents, the water was heated to 50° to 60° C., and, after remaining at this for two hours, cooled to the customary temperature.

1. After 3 hours, calculated from the beginning of the investigation (heating included), it was filtered. The water had an alkaline reaction: 1.14 c.c. 1/10 normal acid were necessary for the neutralization of 100 c.c.

One liter of water contained 26.0 mg. calcium (CaO) and 16.5 mg. magnesia (MgO), corresponding to 4.91 German degrees of hardness.

2. After 6 hours (from the beginning of the investigation as above). Water alkaline: 1.40 c.c. 1/10 normal acid were necessary for the neutralization of 100 c.c.

   One liter of water contains 27.0 mg. calcium and 13.1 mg. magnesia, corresponding to 4.43 German degrees of hardness.

3. After 12 hours (from the beginning of the investigation), Water alkaline: 1.55 c.c. 1/10 normal acid were necessary for the neutralization of 100 c.c.

   One liter of water contained 24.6 mg. calcium and 4.7 mg. magnesia, corresponding to 3.06 German degrees of hardness.

From these investigations it is apparent that the purification increases with the time allowed, and that it is chiefly the magnesia which is precipitated.

The softening of the water during 6 hours, and still more during 12 hours, when the hardness sinks to 3 degrees, may be attributed to complete clarification.

The purification accomplished amounts to 25.4 − 3.1 = 22.3. German degrees of hardness.

TABULATION OF THE ABOVE RESULTS.

Clarification period......	3 hours		6 hours		12 hours	
	Hardness.	Alkalinity.	Hardness.	Alkalinity.	Hardness.	Alkalinity.
Treatment at normal temtemperature..........	7.95°	2.28	6.58°	1.84	6.17°	1.7
At temperature of 50°–55° C...............	4.91°	1.14	4.43°	1.4	3.06°	1.55

From this softening test it follows that the water must remain at least 3 hours in the apparatus, so that a correspondingly uniform softening will be obtained by the treatment in the cold state; and from this we determine the height of the chambers, and, from the previously stated velocity of the rising currents, the dimensions of the clearing chamber.

The higher the clearing chamber, and the broader this is, just so much better is the result of purification. This will depend chiefly on the length of time the water is stirred with the chemicals. But many waters yield precipitates even after more than 12 hours of treatment, and these settle in the pipe-fittings and form lime incrustation, particularly in the bends, which is the harder the longer it is left undisturbed.

This subsequent precipitation can only be restricted by heating the water, or by the addition of an excess quantity of reagents.

Increasing the addition of lime especially serves to accelerate the softening, and therefore, in a softening test, an experiment with an excess of lime should always be made.

The following exposition is an example of this:

From a water which contains,—

(*a*) Bound carbonic acid = .1582° = alkalinity × 2.8
(*b*) Calcium (CaO) = .1476°
(*c*) Magnesia (MgO) = .0500°
Total hardness = 21.76°

For this analysis, and the results of the softening, the author thanks Chief Chemist Grittner of Budapest.

Two series of softening tests were made:

1. With the properly calculated amounts of reagents: when in a cold condition; when warmed to 30°.
2. With the quantity of lime increased about 5%: when in a cold state; when warmed to 30°.

The total hardness and alkalinity of the softening when in the cold state were determined after periods of 1, 2, 3, 6, and 10 hours. (See table of results on page 172.)

The alkalinity is the number of cubic centimeters of $^1/_{10}$ normal HCl which are necessary for the neutralization of 100 c.c. of water. This number multiplied by 2.8 gives the lime degrees.

RESULTS.

Period of clarification in hours.....	1		2		3		6		10	
	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity
Addition of a quantity of reagents according to calculation at usual temperature.....	12°	4.2	9.3°	3.4	6.7°	2.7	6.5°	2.7	6.5°	2.65
At 30 R...........	.....	....	4.5°	1.9						
Addition of a quantity of reagents according to calculation and 5% excess of lime at usual temperature	8.7°	3.3	6.7°	2.8	6.3°	2.3	6.3°	2.3	6.3°	2.25
At 30 R...........	.....	....	5°	2.3						

In the cold purification, with 5% excess of lime, the precipitate settled in granular form very readily and the liquid was entirely clear after one hour.

With this water no difficulty is to be expected when softening in large quantities. The clearing-chamber is calculated to have a duration of passage of one hour. The filtration is only for additional security. Another example is shown with the following water:

Alkalinity.................	9.1°
Calcium....................	.1546°
Magnesia (MgO).............	.077°
Total hardness...............	26.24°

Here the purification proceeds badly; the precipitate is very voluminous.

After six hours it balls itself together, but will not become granular. At three hours the water is always turbid.

With this water a larger clearing-chamber must therefore be used, in which the water must remain more than three hours. The filtration must be very complete. A subsequent reaction in the pipes is to be feared.

Period of clarification in hours.	1		2		3		6		10	
	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity	Hardness.	Alkalinity
Addition of a quantity of reagents according to calculation at usual temperature.	22.5°	6.5	12.8°	4.5	10.7°	4.1	8.9°	3.3	8.5°	3.0
At 30° R.	. . . . .	. . . .	12.1°	4.5						
Addition of a quantity of reagents according to calculation and 5% excess of lime at usual temperature	17.8°	6.4	10.7°	4.5	9.6°	3.7	8.5°	3.1	7.9°	2.9
At 30° R.	. . . . .	. . . .	11.5°	4.7						

This subsequent reaction may only be prevented by the described treatment of Archbutt, as shown in illustration on page 158, Chap. IX, in which the pure water is treated with a current of carbonic-acid gas so that the material (boiler scale formed) precipitated by the subsequent reaction will be dissolved. The water will always be somewhat harder from this treatment, but is completely clear and has lost its alkalinity.

In the installation of a water-purifying plant we must decide whether we will build it on the settling system, while the water is still, or when in motion.

THE SEDIMENTATION AND CLARIFICATION IN STILL WATER.

The above-mentioned settling system is chiefly used for the purification of small quantities of water.

With this system, filters may be omitted, if the liquid is given sufficient time for settling, and if the pure water may flow slowly enough, so that the settled precipitate will not be stirred up and carried along. This velocity of the rising current can be determined by an experiment.

If the withdrawal of water must take place suddenly, an intermediate storage-tank is necessary.

In order to decide whether a single settling-chamber may be used, the following considerations will be of service:

If, during twenty-four hours, there is an hourly demand for pure water of m^3 c.m. for an operating period of a hours, and an hourly inflow of raw water of n^3 c.m. for a period of preparation of b hours, and the preliminary test showed a period of clarification of c hours and a harmless period of discharge of d hours, then, with an area of the clearing-chamber of Fm^2, an effective space R of the same, and a harmless period of discharge of p c.m. per hour, the formula following is correct:

$$24 = a + b + c + d$$

or

$$24 = \frac{R}{m^3} + \frac{R}{n^3} + c + \frac{R}{F_p}.$$

If, for example, during ten hours, 1 c.m. of pure water is used per hour, and 5 c.m. of raw water are admitted per hour, the period of clarification is six hours, and the velocity of the rising current of water is .5 mm. per second, without any of the precipitates already formed being carried along (equal to 1.8 meters per hour); we then have

$$24 = 10 + 2 + 6 + \frac{10m^3}{Fm^2 + 1.8m}$$

or

$$F = .925n^2$$

Period of discharge = 6 hours.

It is, then, possible to accomplish this with a single settling-chamber formed according to Fig. 80.

For the practical accomplishment of the stirring by hand, this chamber would have to be made too high; it must therefore be made with a greater area, and the bottom placed lower down.

By doing so, the velocity of sinking is diminished and the flexible tube given a better chance for extension.

We see in addition, from this example, that it would be better to employ two chambers in the previous case, and arrange for

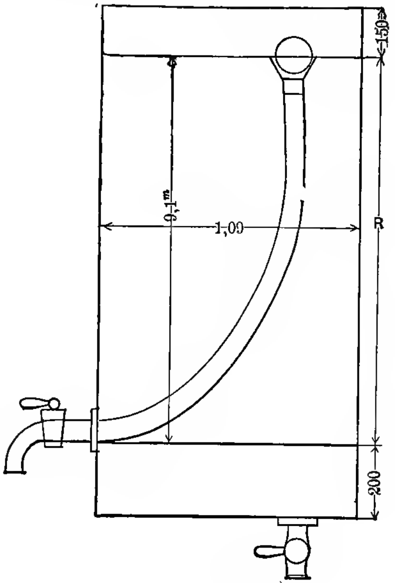


FIG. 80.

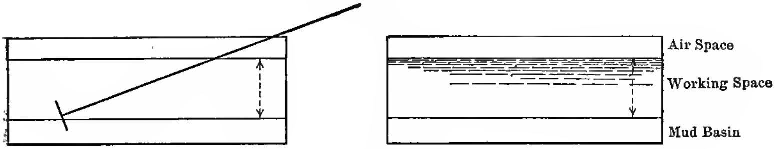


FIG. 81.

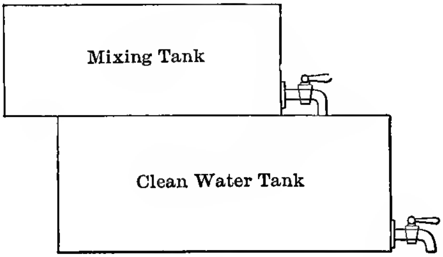


FIG. 82.

smaller outlet tubes, as these are in the way for stirring, and then to carry the outlet pipe only to the middle.

The stirring may be done best in wide troughs, which are arranged beside each other (Fig. 81), or over each other (Fig. 82).

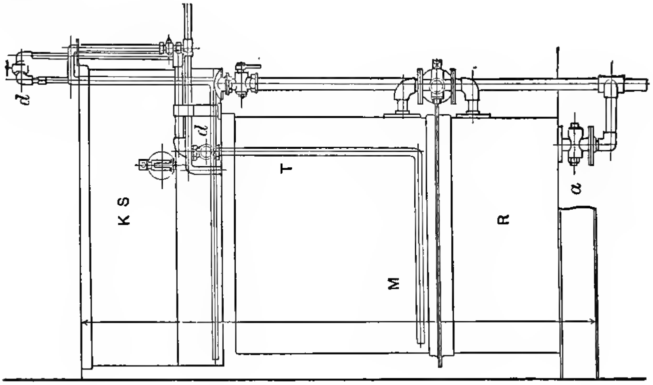


Fig. 84.

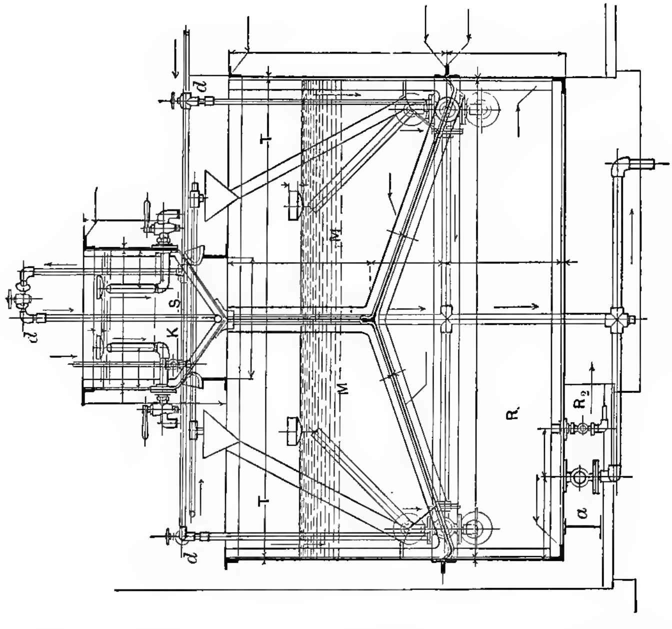


Fig. 83.

The arrangement of the chambers above each other has the advantage that no precipitate settles in the lower chamber.

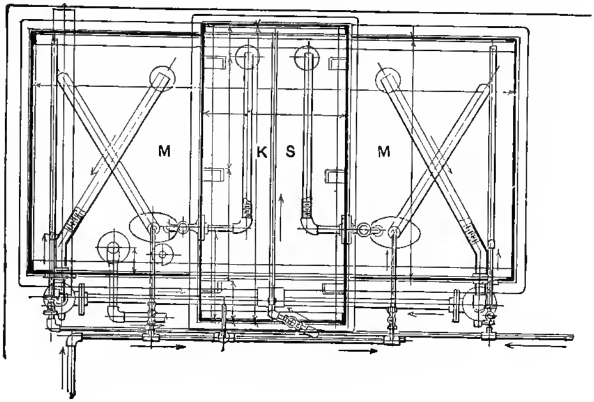


FIG. 85.

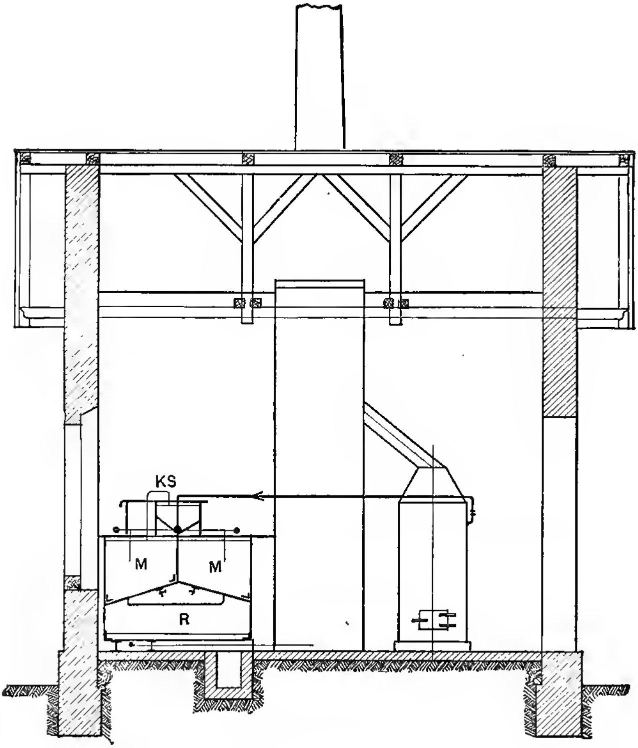


FIG. 86.

Figs. 83–85 show a small water-purifying plant for the operation of a steam-boiler water-station.

The lime and the soda-ash were well stirred with the raw water in the upper trough *KS* by means of a steam and air stirring device (*d*). After clarification the liquid is admitted into the lower chambers *MM* by means of decanting-pipes, which take the reagent liquid from the top surface. The ends of the decanting-pipes are shown with floats, and are lifted out before the water is drained out.

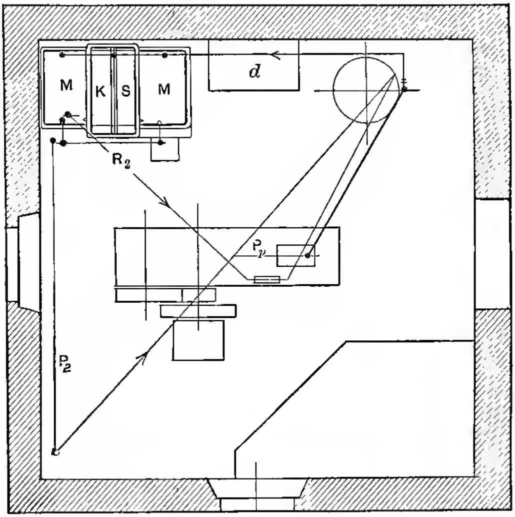


FIG. 87.

The reagent liquid thus discharged enters a funnel-pipe and mixes itself with raw water, which is flowing in at the same time. The mixed water thus produced will be well stirred by two other steam and air stirring devices. After complete clarification the pure water will pass by means of decanting-pipes into the space below.

The steam and air stirring apparatus consists of nothing other than a jet of steam placed at a corresponding depth in an open pipe.

From Figs. 86 and 87 the arrangement of this small softening apparatus is apparent.

If the outlet valve is opened gently, and if the liquid is completely clear, the decanting-pipes may be dispensed with.

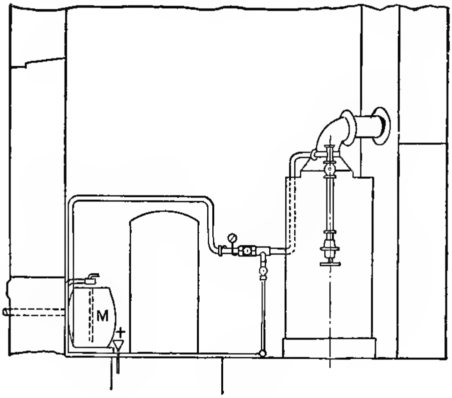


Fig. 88.

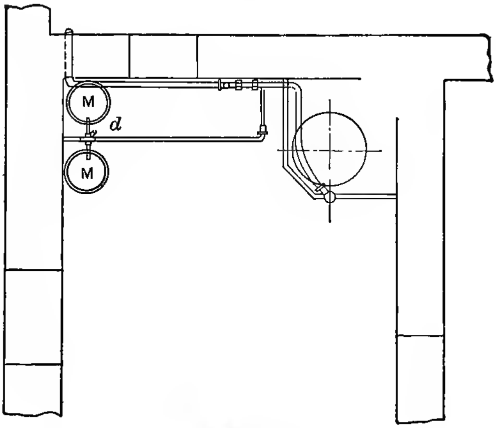


Fig. 89.

Figs. 88 and 89 show a still simpler arrangement of such an apparatus, in which the water will be alternately treated in two chambers.

The treatment (with lime and soda-ash) takes place while the water is hot.

The stirring takes place by means of numerous perforated wooden disks in whose center is placed a bar, moved up and down in the same.

After clarification the water is admitted through wooden pipes, placed so high the precipitate will not be carried along, into a lower reservoir.

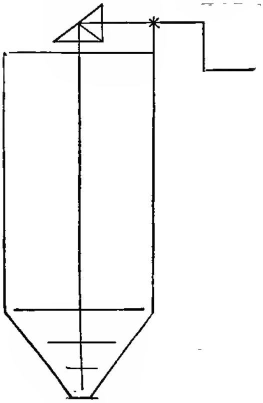


FIG. 90.

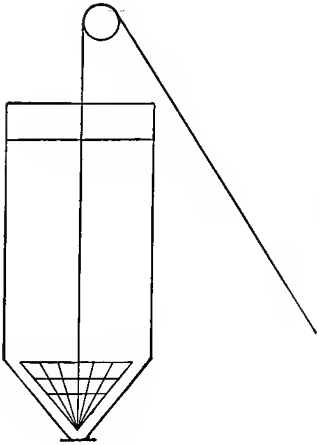


FIG. 91.

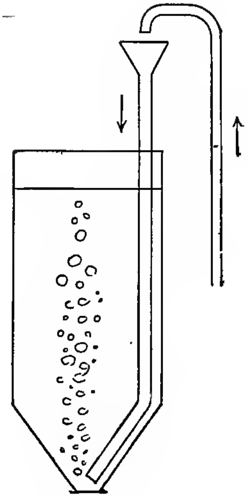


FIG. 92.

For larger quantities of water than about 8 to 10 c.m., hand-stirring is not possible, and a stirring device with stirring motion, Fig. 90, or a stirring device with up-and-down motion, Fig. 91, or, lastly, an air-stirring device, is used, Fig. 92.

In both the first cases, the bottom of the mixing-chamber may be flat, although the removal of the precipitate is best accomplished by a funnel-shaped bottom.

In the latter case the bottom must be funnel-shaped, in order to always convey the chemicals to the point of entrance of the air.

In Figs. 93, 94 is shown a small water-station with stirring devices (these may also be equipped with rotating stirrers).

In Figs. 95, 96, is shown an apparatus with air-stirring device.

The water is forced, by means of a pulsometer, into a division of the top reservoirs.

From this division it descends—carrying air with it—alternately into the two settling-chambers, and from these through the filters into the cistern, from which it will be raised by means of an ejector into the highest reservoir.

From this it is delivered to the locomotives in the usual manner.

The chemicals will be added by hand to the mixing-chambers.

In Fig. 97 is a similar plant shown, in which a steam-boiler is located.

The reagents will be first placed in a closed chamber (*KS*), and then forced by steam into the mixing-chamber.

In small railway water-stations it often happens the charges are added in a few minutes to the raw water at the same time as it is being pumped by the pulsometer, during the short stay of the locomotive at the station, while the preparation of the additions and the clarification of the treated water occurs in the pauses, as, for example, between the last and first daily trains.

In this case, and when the reservoirs stand high, the necessary quantity of lime and soda for the contents of the clearing reservoirs will be placed in correspondingly shaped vessels and forced into the reservoirs by steam from the locomotive, where they become violently stirred with the raw water by the air carried along.

In order to accomplish a good mixing, the bottoms of the reservoirs must be funnel-shaped.

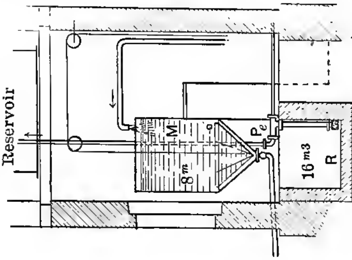


FIG. 93.

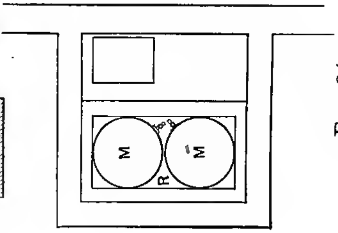


FIG. 94.

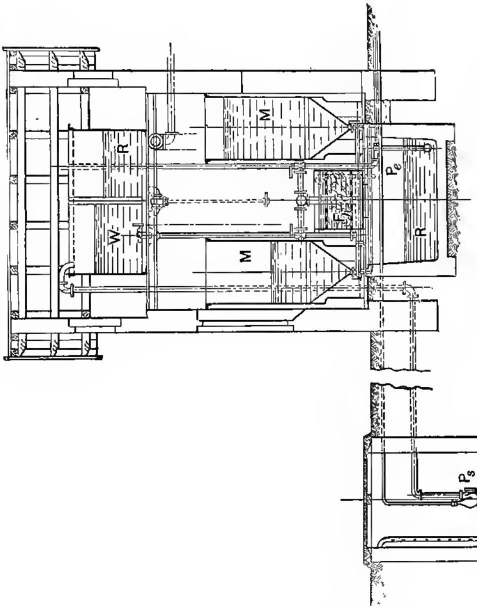


FIG. 95.

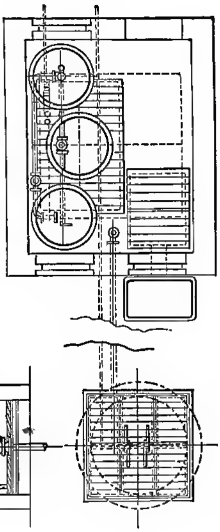


FIG. 96.

In case the water cannot flow by gravity from the water reservoir into the tender-tank of the locomotive, but must be forced to the same by an injector, the additions will be added by hand to the reservoir. This is the simplest and cheapest form of water-purifying for railway water-stations.

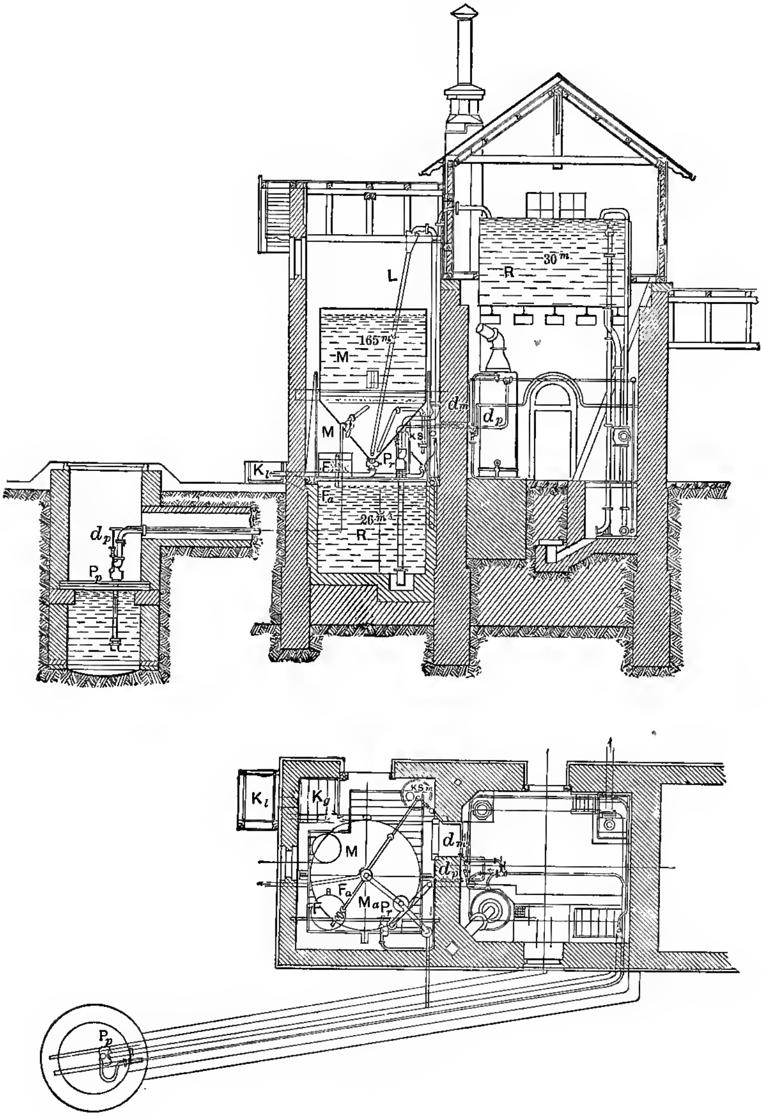

L
R
30 m.
165 m.
M
M
d_m
d_p
KS
P_r
K_l
F
F_a
26 m.
R
d_p
P_p
K_l
K_g
KS
M
d_m
d_p
F
F_a
M_a
P_r
P_p

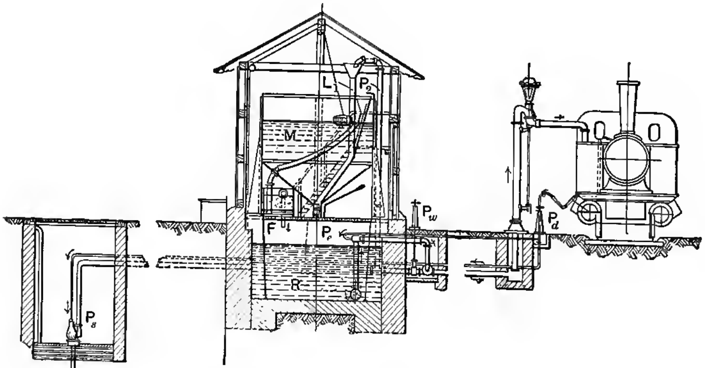
FIG. 97.

In the following, two such plants are described, in which the addition of the chemicals to the water was made by hand.

In Figs. 98, 99 is shown the mixing-chamber in a frame house.

The steam of the locomotive can be conveyed by means of the three-way valve P_d to the pulsometer, which forces the raw water into the mixing-chamber M, and to the injector which forces the pure water into the locomotive. It is also possible to simultaneously set in operation the pulsometer P_s and the injector P_e.

Fig. 98.



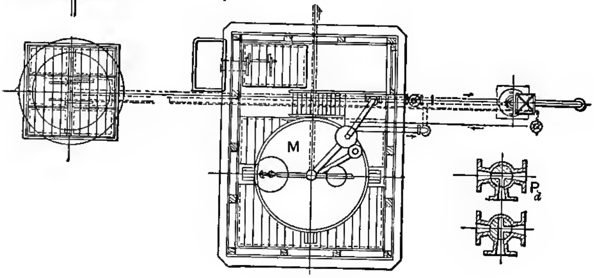


Fig. 99.

The entering water from the rising pipe in the waste-pipe of the mixing-chamber carries a great quantity of air to the lowest point of the funnel-shaped bottom of the mixing-chamber, and stirs the reagents with the raw water during the whole time the raw water enters.

During this period of admission of water and the stirring, the outlet pipe, connected with a float by a cord and chain over rollers, is so suspended from a hook that the float will be reached by the water shortly before the chamber is filled. The chain will then slacken, the ring swings itself free from the hook (see Fig. 43, page 123), and the discharge of the water begins without further help.

As the water first coming from the outlet is still turbid, a filter is placed between the outlet hose and the pure-water cistern.

FIG. 100.

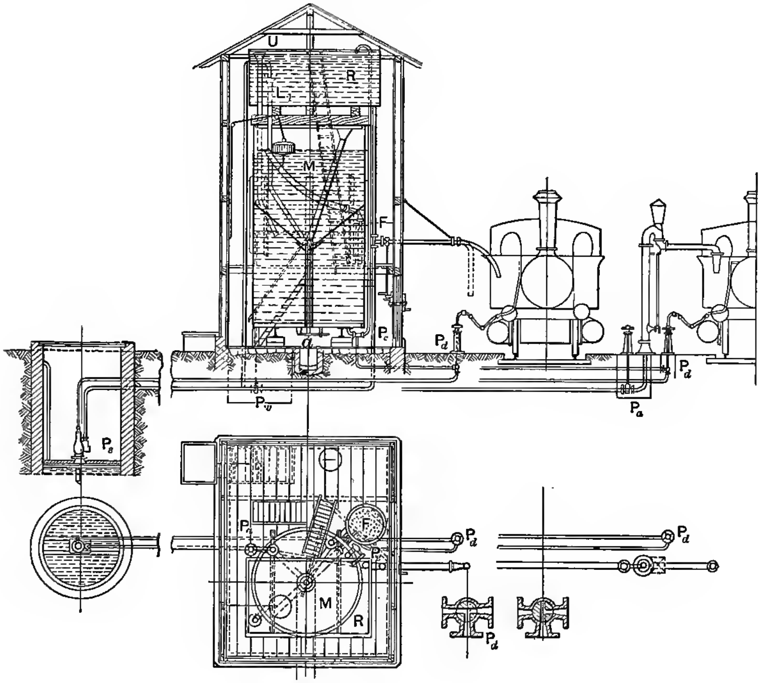


FIG. 101.

If we dispense with the automatic discharge of water, the filter may be dispensed with.

In Figs. 100, 101, by placing a pure-water chamber over a mixing-chamber, means are provided that the water can flow to the locomotive without further mechanism.

This plant is, therefore, more generally used than that previously described.

The water reservoirs are all made of thin plates and placed above each other, so that the house will contribute in no way to the support of the upper chamber, and therefore can be built very cheaply.

The addition of the reagents takes place usually in the settling systems, in that the lime is taken in the form of burnt lime and then dissolved. We usually assume that the burnt lime contains 80 to 90% of effective calcium.

We must therefore use 20 to 10% overweight.

The soda-ash will usually be dissolved before the addition to the raw water, and the solution takes place most quickly in warm water.

Caustic soda will be added, dissolved, and created by means of stirring milk of lime with hot soda-ash solution.

THE SEDIMENTATION AND CLARIFICATION IN FLOWING WATER.

When the time allowed for the water requirement, and the addition of reagents to the raw water, is very small, and the quantity of water required in a certain time must therefore be proportionally large—as, for example, in the case of filling the tender with a pulsometer—then the sedimentation system in still water recommends itself.

There will then be sufficient time for the clarification of the treated water, and therefore the results of the purification will be the best possible. Filters will be usually dispensed with. But if the time at hand for the water requirements during the day is not restricted, or only a little, and when larger quantities of water are to be purified, then the settling of the precipitates must occur in flowing water, because the tanks for the settling in still water would have to be too large. But these tanks will be the smaller and cheaper the better the time at disposal is utilized, and also when the water requirements and water treatment is continuous both day and night. If, for example, 1200 c.m. are to be purified daily, the purifying chambers would be the smallest possible if $\frac{1200 \text{ c.m.}}{24 \text{ hours}} = 50$ c.m. per hour were to be required and purified.

But in this case, also, the correspondingly best results of purification will be accomplished when, for a certain size of purifying tank, the water in the same can be delayed the longest, and when the hourly performance is the minimum.

This presumes that no pauses for rest-periods of the attendants, and for changing the treatment during the operation of the apparatus, occur. The double arrangement of preparing tanks for the chemicals and the placing of these preparing tanks on the ground floor, aids in the fulfillment of these conditions, especially when operating both day and night. The charging of the apparatus, which then must be closed up with lime and soda-ash, the removal of the precipitate, and the cleansing of the filters by the attendants, can be conveniently and quickly accomplished. Besides, it is especially necessary to place the lime-charging tank below, while the soda-ash distributor, which must be attended to more seldom, may be placed above. If the clearing-chamber itself has a small height, the addition of the reagents may of course also take place from above without loss of time, and closed chambers will be unnecessary. From the point of view of the place of attendance, there results a classification of water-purifying plants into those which are operated either entirely or in part from above, or those in which the operation occurs from below.

In Figs. 102–105 three water-purifying plants are shown, in which the operation is accomplished above the clearing-tanks.

Figs. 102, 103, 104 display the arrangement of a railway water-station, in which there had been installed water-purifying apparatus of an older type.

W, *M* are the old parts, *R*, *K*, *S*, *F* are newly installed tanks.

The lime-saturators are placed one behind the other and were designed for a continuous stream of water to pass through, because little lime-water was necessary, it was not continually pumped, and two of them were already on hand and it was desired to use them again. The existing raw-water tank *W* was divided, in order to bring the decanting-pipes below. The filter was suspended from the platform.

By the use of a decanting pipe in the old lime-tank, the simple arrangement without change to the building makes the quotient $\frac{K}{M} = \frac{\text{Cost of plant}}{\text{Delivery of treated pure water}}$ very satisfactory.

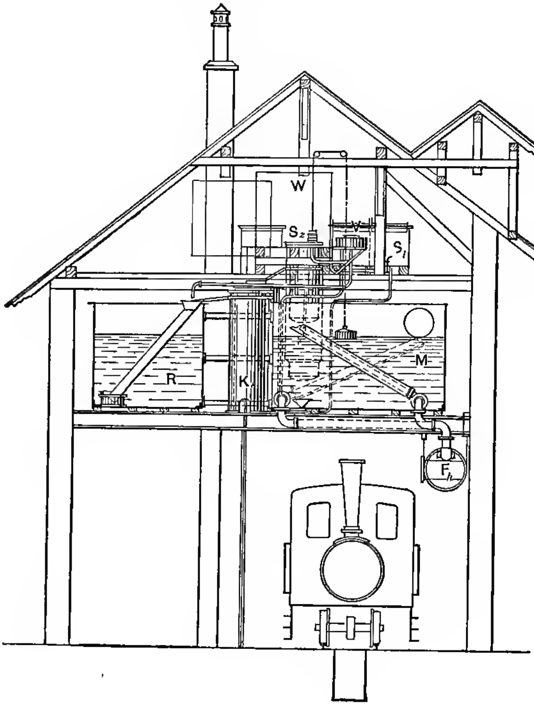


Fig. 102.

Fig. 105 shows a water-purifying plant which is used by a factory. With this plant $\frac{K}{M} = .2$ (*K* in kroners (about 22 cents), *M* in liters).

On the first operation of this plant the injectors of the boilers which were fed with pure water showed a heavy deposit of lime, which on a proper arrangement of the distributor disappeared.

Without a careful analysis of the pure water previously taken, the error would be recognized from the results of the following simple titrations and determinations of hardness.

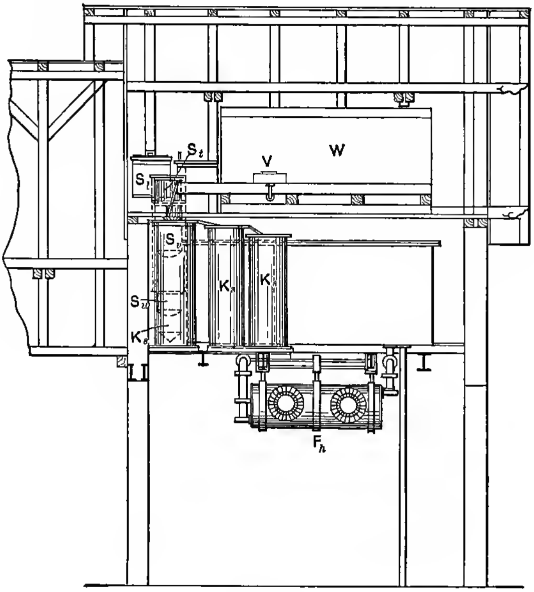


FIG. 103.

Day.	Hour.	Hardness of		Alkalinity.
		Lime-water.	Pure Water.	
March 22, 1901	7.30 A.M.	124°	4.5°	2.9°
" " "	8.30 "	127	4.8°	2.8°
" " "	9.30 "	123°	4.5°	2.8°
" " "	11.30 "	185°	4.4°	2.8°
" " "	1.30 P.M.	125°	4.0°	2.8°
" " "	4.30 "	123°	4.2°	2.9°

As the hardness of the pure water consists of the hardness remaining in the water and of that resulting from the excess of lime, it must be assumed that about 2° to 2.5° hardness will persist in the water on account of soluble carbonates of lime and magnesia, therefore the lime excess is $4.2-2.5° = 1.7°$.

By a corresponding change of the respective divisions of the weir-distributor the quantity of lime-water was properly adjusted.

As the division of the weir-distributor for the lime-saturator amounted to 142 mm., and 20° CaO was to be added to the water, the dividing partitions were to be moved as 142 mm.: $20 = x$ mm.:1.7°, therefore it was to be moved 12 mm.*

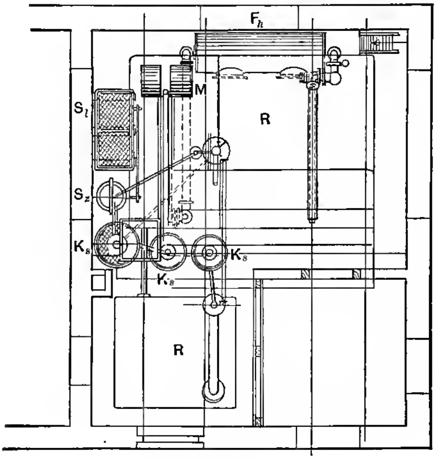


Fig. 104.

In Fig. 106 is shown a peculiarly arranged water-purifying plant at a railway water-station, in which the interior reservoir contained an outer annular space for raw water, an inner annular space for pure water, and in the latter a Dervaux purifying apparatus with lime-saturator (built in the center) was placed.

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* The same object can be accomplished if we move the divisions of the weir to different clamps. The details appeared in the Zeitschrift für Bierbrauerei and Malzfabrikation, XXXII, Nos. 48 and 49 in the article "Die Wasserreinigung nach Patent Wehrenfennig in der Brauerei Simmering-Wien von Georg Meichl jun.

A result worthy of imitation does not appear to have been obtained from this plant.

In Figs. 107–115 are shown three plants erected, in which

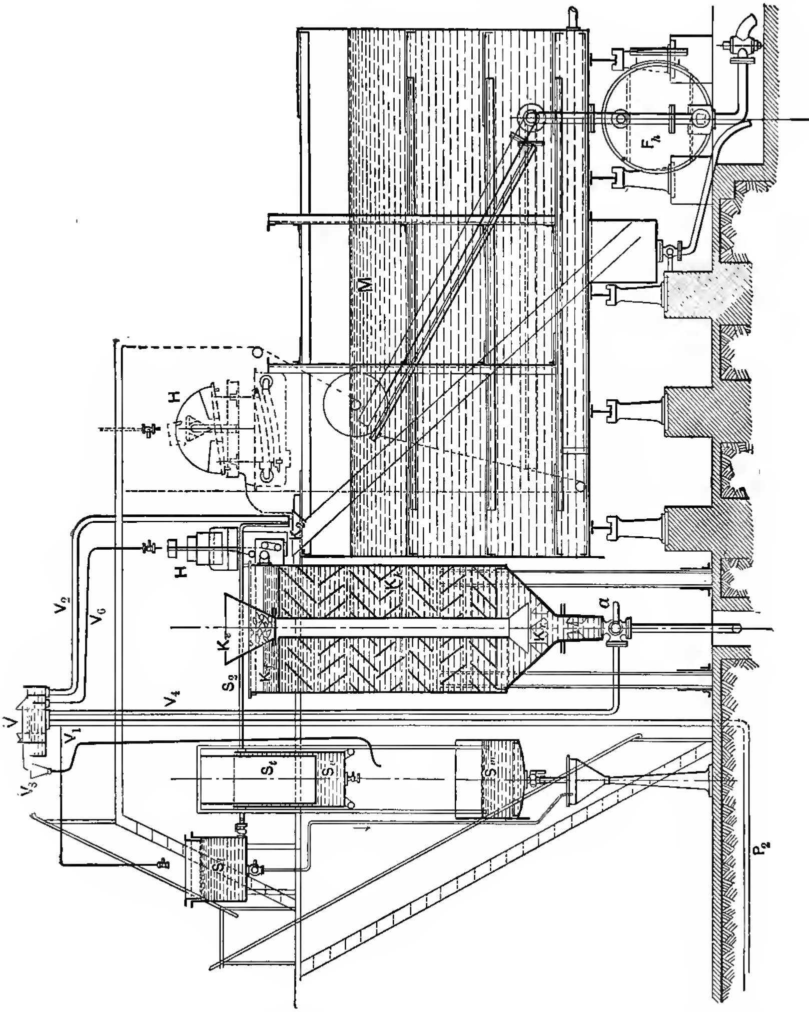

FIG. 105.

the lime was to be distributed from a platform to the lime-tank approximately 3 m. high. The soda-ash was mixed with the lime. The reagent water formed from the lime-water and caustic soda was conveyed by means of a pump to the point of mixture.

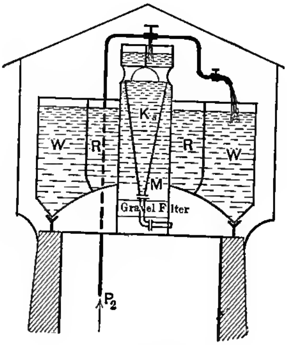

FIG. 106.

The following is the description:

Referring to Figs. 107–110. In the building containing the machinery apparatus an iron reservoir divided into two similar chambers is placed on the second floor.

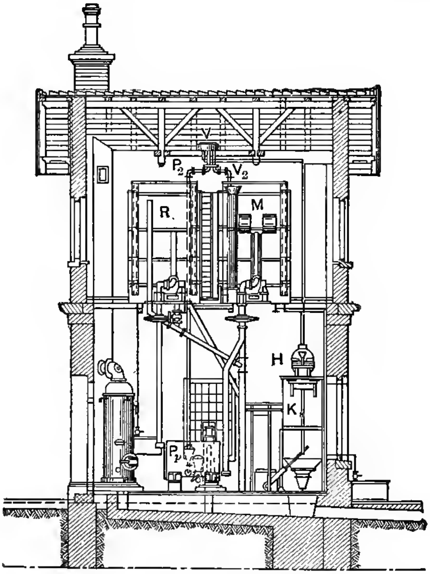

FIG. 107.

Above the former, in the roof space, is placed a water distributor *V*, while on the ground room is the boiler, a pump

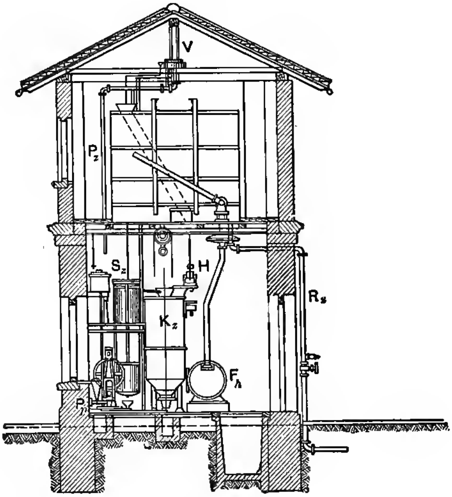

Fig. 108.

P_p, a lime-water preparing tank *K* with float chambers, a filter F_h, and an iron platform two meters high with stairs, on

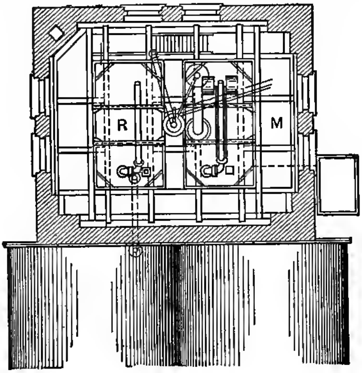

Fig. 109.

which the two troughs for dissolving the soda-ash S_z and the soda-ash distributor are placed.

In the bottom of the building a small lime-pit is placed, which may be filled from a lime-slaking trough placed outside the building.

The steam-pump sucks the raw water from the cistern, and forces it through the uptake pipe into a chamber to the so-called distributor *V*, which is shown with a circular weir and surrounded by an annular space.

The distributor has the duty of dividing the water automatically into three parts in proper proportion to the analysis, and which are:

(*a*) Into that entering to be mixed with the solution of reagents and to be changed from raw water to pure water.

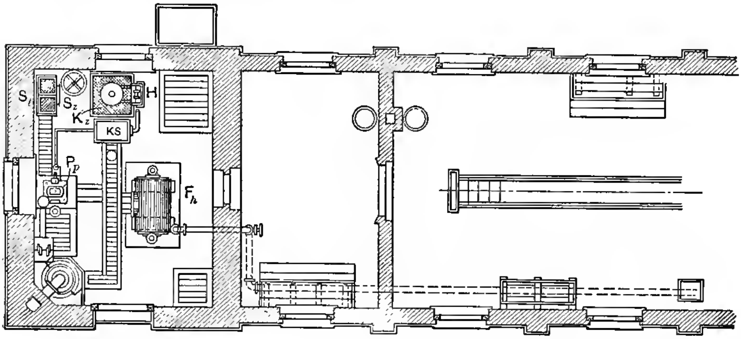

FIG. 110.

(*b*) Into that required for preparation of a clear saturated reagent solution.

(*c*) Into that required for displacing an equal quantity of dissolved soda-ash, and is only used for this purpose.

The portion (*a*) and by far the greatest quantity of raw water flows from the distributor through a short pipe into the receiving funnel of a large inclined pipe and through this into the division *M* of the high reservoir.

The portion (*b*) of the raw water (about 1/7 of the portion *a*) flows into the lime-tank *K*, and is energetically stirred in the same with slaked lime by means of an air-stirring device.

The portion (*c*) of the raw water (about 1/500 of the portion *a*) flows into the soda-ash distributor, out of which it is conveyed to the bottom of the lime-water chamber.

By means of the admission of the soda solution to the mile in chamber *K* it will be changed to caustic soda (causticized).

The liquid produced in *K* clears itself by rising and flows as a clear mixture of lime-water and caustic soda—as so-called reagent water—into a float-chamber. In this float-chamber is a float balanced from above. The latter regulates, by means of a chain, a by-pass valve *W* of the reagent pump, so that the latter always delivers the determined quantity of liquid for the formation of the addition water which flows out of the distributor, Fig. 111.

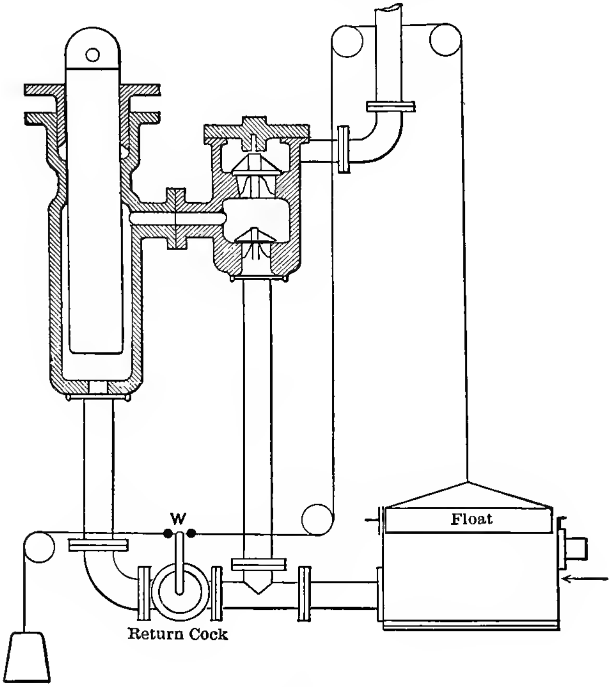

Fig. 111.

By a greater inlet into the vessel the float is raised, partially closing the by-pass valve, by which the pump will pump a correspondingly greater quantity. By a less inlet, the float sinks and the opposite will occur.

From the float chamber the reagent water will now be forced by the so-called reagent pump, attached to the main pump, to the mixing-place, where it joins with the raw water (portion *a*) and flows down with this through the inclined pipe mentioned into the reservoir division *M*.

In this large division, in consequence of the small velocity of the rising current of the water, a close and continuous contact of the reagent water with the raw water occurs, and therefore a most complete precipitation of the material takes place. The precipitate thus formed remains for the most part on the bottom of the reservoir division.

Only the very fine precipitates, which will be carried along in spite of the small velocity of the rising current, reach the top surface of the water in the reservoir division *M*, and flow from there with the pure water through a decanting-pipe into the filter *F*, in which they will be held back.

The water flows now, entirely pure, through the pipes and the second decanting-pipe into the reservoir division *R* of the double reservoir, and will flow from here to the water crane.

In proportion as the pure water is taken from division *R*, the water flows from division *M* into division *R*, so that the contents of both reservoir divisions are available for pure water.*

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* The result of the water-purification depends on the proper measurement of the additions, which is possible by strict observance of the prescribed mode of operation, as well as on a proper mixing, besides the longest possible reaction of the added materials on the raw water, and on good clarification and perfect filtration.

The longest possible action of the reagents on the raw water and a good clarification may be accomplished if the clearing-vessel has the greatest possible area, and if, in addition, a reservoir placed above is used.

Then, because the heavy precipitate does not enter the filters, the latter will only be a little burdened with the very fine particles. We can on this account use wood-fiber as a filter-bed, and suffer no daily loss of water through washing out the filter. The resistance to passage in the wood-fiber filter is so little that the two high reservoirs do not have to be placed at different

For a plant of 6 c.m. per hour, the quotient of $\frac{K}{M}=.5$.

The following are the calculations for the previously described water-purifying plant:

1. Chemical Characteristics of the Raw Water.

The raw water contains:

	Per Liter.
Bound carbonic acid. . . .	.1056 grams.
Calcium (CaO).	.1284 "
Magnesia (MgO).	.0078 "

Calculated to German degrees of hardness (see page 8), this gives:

Bound carbonic acid. . . .	13.44° German
Calcium.	12.84° "
Magnesia.	1.09° "

The absolute hardness, therefore, amounts to

$$12.84+1.09=13.93^\circ \text{ German.}$$

2. The Ascertainment of the Required Quantities of Additions.

For ascertaining the required additions of lime and caustic soda for softening water, the formulas developed from the basis

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elevation. As, in spite of the use of a division M of the high reservoirs as a clearing-chamber, the water treated therein will flow through the filter into the reservoir from which pure water is delivered, and this takes place not only during the demands for water, but also while the pump is at a standstill, if the level of the surface sinks in the water-outlet tank,—on this account there are present all conditions for the attainment of a perfectly pure water, the greatest possible storage of water, and, by the saving of a special clearing-chamber and of a special building, the desired cheapness of the plant is obtained.

The construction of the hinged decanting-pipes is protected in Germany by D. R. P. 104,547, and in Austria with Priv. $\frac{48}{4262}$. Patents have been obtained in Austria for the distributor, lime-chamber, soda-distributing tank, and tilting vessel.

and theory of Professor Stingl by Professor Kalmann are of assistance (see *Organ für die Fortschritte des Eisenbahnwesens*, 1893):

$$2a-b=m$$
$$c-a=n$$

For these it is important that—

(*a*) The bound carbonic acid be calculated in German degrees of hardness.
(*b*) The quantities present in the raw water be calculated to calcium (CaO) in German degrees of hardness.
(*c*) The total hardness be calculated in German degrees of hardness.

m = the required quantity of lime.
n = the required quantity of caustic soda.

By substitution we therefore have

$$m=2a-b=26.88^\circ-12.84^\circ=14.04^\circ$$

as the required quantity of lime (CaO),

$$n=c-a=13.93^\circ-13.44^\circ=.49^\circ$$

as the required quantity of caustic soda.

Inasmuch as caustic soda as such will not be used, but will usually be produced from lime and soda-ash, and as 1° of caustic soda is created by 1° of soda-ash and 1° of lime, .49° of caustic soda requires .49° lime and .49° soda-ash.

(*a*) *Ascertainment of the Lime Addition.*

Altogether, according to the preceding, we require:

$$14.04+.49=14.53 \text{ lime.}$$

The discharge of the water-purifying plant amounts to about 6000 liters per hour (6 c.m.).

Inasmuch as 1 liter requires 14.53° or 14.53 cg. of lime, there are 6000×14.53=87180 cg., or approximately 872 grams of burnt lime required during each hour of pumping.

As it is best to add the lime in the form of clear saturated lime-water, and 1 liter of lime-water contains 1.2 grams of CaO, and for 6000 liters of raw water 872 grams of CaO are required, we must add to 6000 liters of raw water $\frac{872}{1.2}=727$ liters of clear saturated lime-water.

(*b*) *Ascertainment of the Soda-ash Addition.*

According to the preceding calculation, .49° of soda-ash is to be added to the raw water, which requires a solution of $\frac{53}{28}\times .49$ cg. of soda-ash per liter.

If now a soda solution of 250° were used, we have the following:

The requirement for 6000 liters per hour of pumping is in the proportion of $.49° : 250° = x$ liters : 6000 liters; $x=\frac{294000}{250}=$ 11.76, or, in round numbers, 12 liters of 250° soda-ash solution.

As 1 liter of 250° soda-ash solution contains 250°×2= 500 cg. or 5 grams of soda-ash, therefore, for each hour of pumping, 12×5=60 grams of soda-ash are required.

Each soda-ash trough of this plant contains 100 liters: for the preparation of 100 liters of 250° soda-ash solution 100×5=500 grams=1/2 kg. of soda-ash is required, and the solution of this quantity is best effected by the water standing below (see page 108).

From the above it is seen that the raw water is to be treated with lime-water and soda-ash solution in the proportion that 6000 liters of raw water will be treated with 727 liters clear saturated lime-water and 2.94 liters of 1000° soda-ash solution.

This is accomplished with a Wehrenfennig distributor, in which the water flows over a weir, which is so arranged that the length L is divided in three parts in the proportion

$\frac{L}{6000 \times 727 \times 12} \times 6000 = .890 \times L$ for the raw water;

$\frac{L}{6000 \times 727 \times 12} \times 727 = .1087 \times L$ for the lime-water;

$\frac{L}{6000 \times 727 \times 12} \times 12 = .00178 \times L$ for the soda-ash solution.

The raw water flows direct to the lime chamber, saturates itself in this with lime, clears itself, and flows then to the mixing-place.

The calculated quantity of water for the soda-ash solution is collected as operating water in the Wehrenfennig water-purifying system, in which it forces an equal quantity of soda-ash solution to the point of mixing.

For the attendance of the preceding plant and similar plants the following direction may be of value:

Attendance of the Machine.

1. *Storage of the Reagents.*

1. The lime is to be dissolved in the lime-slaking trough, stirred well, and to be kept always under water in the lime-pit.

Stirring of the lime or of the reagent water with the hand is to be avoided, as both act caustically.

2. The crystallized or ammonia soda-ash of about 95% must be kept in a dry room.

2. *Preparation of the Pumps.*

Before starting the pumps, the decanting-pipe in the chamber *M* must always be raised, and the ring of the chain placed on the hook, so that the uncleared water cannot flow to the filter.

The soda-ash will be most uniform for each troughful if placed on a sieve and the water admitted to the soda-ash from below. The soda-ash solution thus formed must have a definite strength, and will be admitted to the soda-ash tank before starting the pumps.

For this purpose a soda-ash distributing apparatus, according to Figs. 35 and 36, is used,—

(*A*) First, by opening the cock to the lower chamber until this is completely empty.

(*B*) The soda-ash solution will be admitted from one or the other of the soda-ash troughs into the stationary chamber until the discharge from the outlet pipe into the lime-saturator begins.

(*C*) After this has been done, the cock in the lower chamber is closed again.

The lime-saturating chamber is to be cleaned out before each operation of the pump, while about 25 liters of water pass through it. Half-thick lime-paste is placed in the upper funnel of the lime-saturator.

After these preparations the pump is started.

3. *Consumption of Chemicals.*

The lime and soda-ash required is dependent on the composition of the raw water.

4. *Maintenance and Purification.*

It is to be noted that the partitions fit tightly in the annular space of the distributor.

Arbitrary moving of the partitions by the attendant is to be strictly prohibited.

The clearing-chamber *M* is to be cleansed every two or three months. For this purpose, after lifting the decanting-pipe, the wash-out valve in the bottom of the chamber is opened, and, while the precipitate is stirred up, water is passed through.

At this opportunity a careful examination is to be made of the decanting-pipe, the chain and rollers, the floats, and all other parts usually under water.

During the cleansing of the clearing reservoir *M*, raw water may be pumped into the division *R* of the reservoir through a nozzle.

The division *R* is to be washed out two or three times a year. Damaged painting of various parts is to be renewed as needed.

If the filter no longer yields clear water, the contents of half-fine wood-fiber must be changed.

Washing of the filter is not to be permitted, as the water flowing quickly through it may tear holes in the contents.

The renewal of the filters takes place after both decanting-pipes are lifted from the water.

The filter as well as the pipes will be emptied through the cock at the bottom of the filter, the cover will be opened, the old filter fiber removed, and new wood fiber pressed in uniformly, but not too tight.

Following the blowing-out of the decanting-pipe of *M*, the air-cock to the filter chambers is to be held open until water flows out and then closed.

On account of a good clarification in the reservoir *M*, only very little material enters the filter, so that a renewal of the wood fiber is sufficient for 4 to 6 weeks where the plant works daily.

As to the lower part of the lime-saturating chamber, the outlet from this, as well as the central pipe, these are to be cleaned about twice a year.

The removal of the precipitate is effected by turning the three-way cock from the position when working to the position for removal of the slime. For cleansing, the three-way cock is placed in the third position, while at the same time the ordinary valve beside it is opened and the incrustation taken away.

The floating part of the soda-ash chamber must rise easily; the rollers are to be greased at intervals.

The trunnions of the tilting-chamber are to be oiled regularly; the discharge and the inlet are to be kept clean.

All valves are to be cleaned from time to time by the by-pass valve of the "reagent" pump at least once in three months and smeared with graphite paste.

Fig. 112 shows a similar water-purifying plant for a small railway station. The reservoir M was on hand, but it was given a depth of 2.5 meters by placing around it a sheet 1 meter high, so that the mixing and clearing could take place in it.

The pure-water reservoir was newly built.

The necessary buildings were confined to the installatio of a canal to carry away the refuse, and the lime-pit $\frac{K}{M} = .2$

In Figs. 113 to 115 is shown the arrangement of water-purifying devices for a small railway water-station, on whose lower floor the operating-machine and the testing-stand are placed. It will purify 15 c.m. of water per hour.

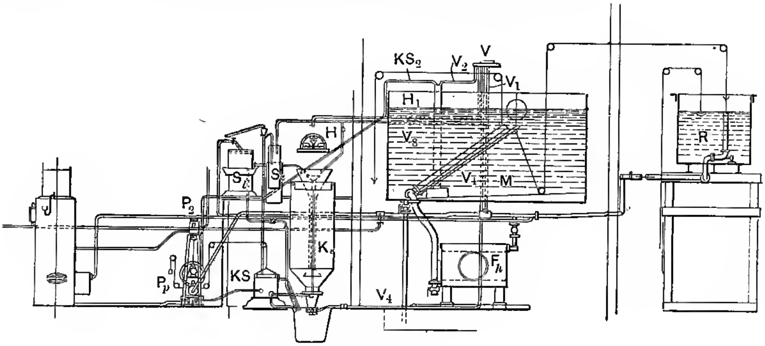

FIG. 112.

In spite of placing the different devices below in the free space under the reservoir, the arrangement is not crowded together and is easily accessible.

As a small pump was present, it was used as a reagent pump and was attached to the pumping-engine.

The soda-ash was conveyed to the lime-saturating chamber, and therefore the purification was effected by a mixture of lime-water and caustic soda.

The filter is a wood-fiber filter, in order not to have to raise the mixing-reservoir, and not to lose any water in back-washing.

The quotient of economy $\frac{K}{M}$ is small, therefore very advantageous, and amounts to .04.

In Figs. 116-125 the lime-distribution takes place from closed chambers on the ground floor; the distribution of soda-ash, on the contrary, takes place from above. In all three types shown, decanting-pipes are used, which make the quotient of economy $\frac{K}{M}$ very satisfactory.

Figs. 116 to 119 show a railway plant in which 20 c.m. of water, having a hardness of 43° according to Case 1, are purified per hour.

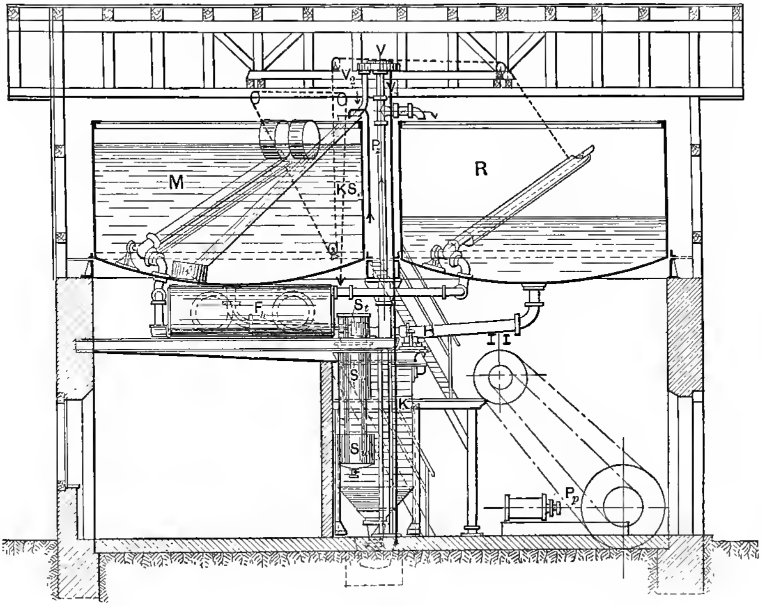

FIG. 113.

The entire building and the reservoirs *M* and *R* were present. A wing did not have to be built.

The handling of the lime has to be done on the ground floor, as the water is very hard, and a very large lime addition is necessary.

The soda-distributor was placed above the reservoirs, on account of the cheapness of the installation, and added by means of the apparatus shown in Fig. 37.

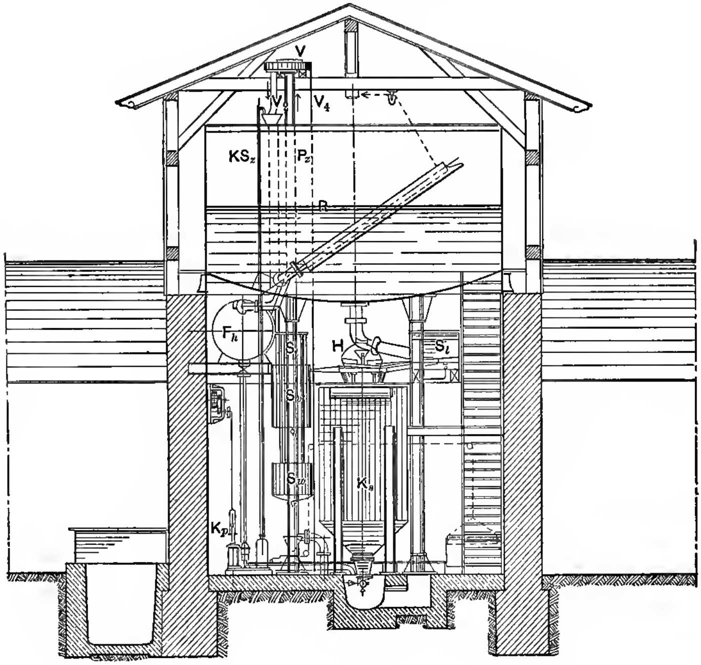

FIG. 114.

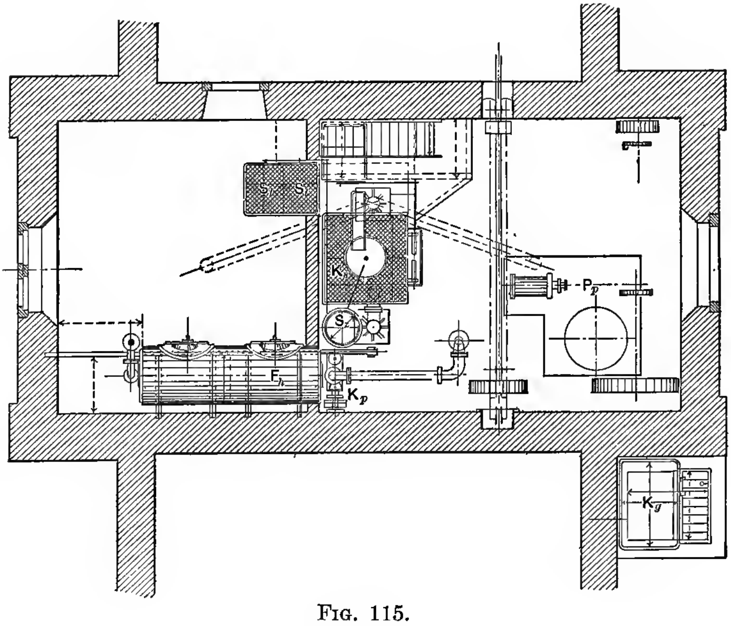

FIG. 115.

By the installation of a floating apparatus, as shown in Fig. 36, a reserve would be created.

The floating apparatus was so constructed that the ballast-water was led into the vessel S_t, and therefore it must always be raised up before refilling. (In later installations this water-chamber was placed below, and the water can be let out by a waste-valve.)

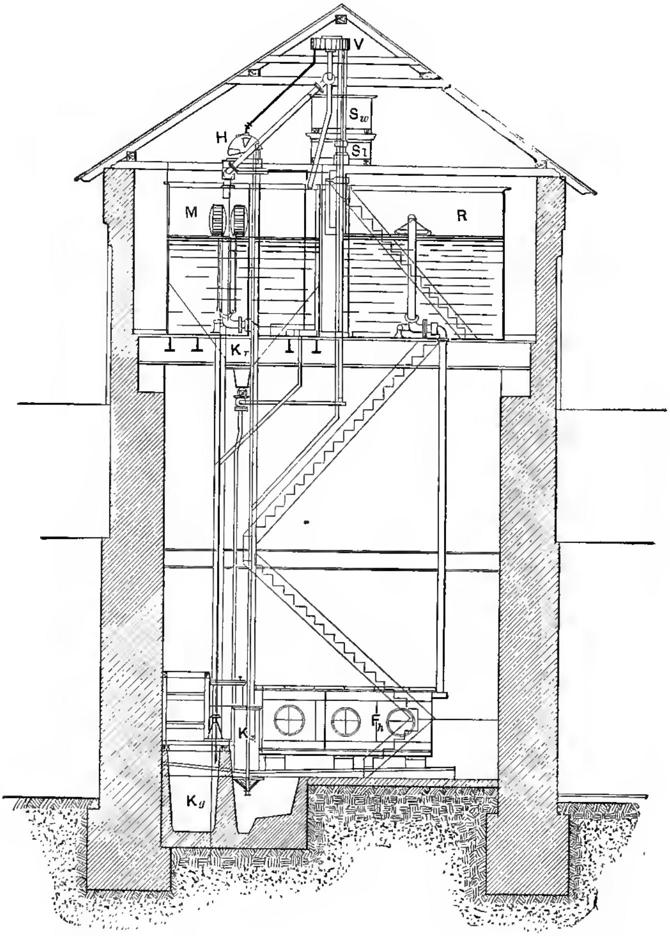

FIG. 116.

It is recommended for similar installations, where the reservoirs are placed high up, to always have the preparation of the soda-ash take place on the ground floor.

The quotient of economy $\frac{K \text{ (in kroners)}}{M \text{ (in liters)}} = .07.$

In Figs. 120 to 122 is shown the reconstruction of a plant in which the vessels W, K_s, M, proved satisfactory, and in which the conical-shaped shallow filters placed in the high vessels were not sufficient, and the uniformity of the lime-water was all that could be desired, even for a longer duration of operation.

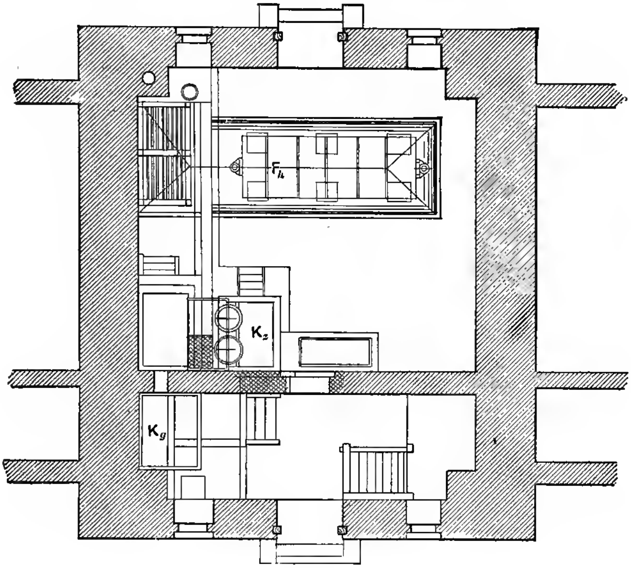

FIG. 117.

For the improvement of the plant, the lime-saturating chamber was divided by a central partition, and the intermittent operation was carried on in either of the divisions thus formed.

The intermittent inlet of the water into the lime-saturating chamber took place by means of a tilting-vessel, *H*.

The distribution of the lime took place from the lime-distributor K_s placed on the ground floor; the soda distribution took place by means of the apparatus S_z (Fig. 36, page 109). Mixing took place in the central pipe of the high vessel M which is in communication with the high reservoir.

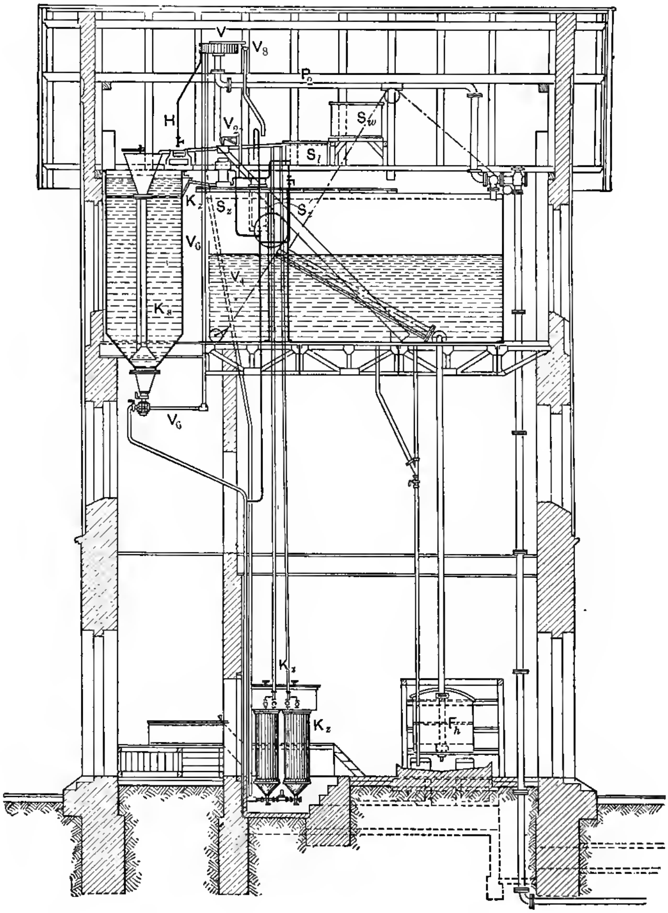

Fig. 118.

Through these devices and the installation of the decanting-pipe, the regular quantity of pure water at disposal would be increased by the contents of the upper part of the high vessels (which always remain clear), and the quotient of economy $\frac{K \text{ (in kroners)}}{M \text{ (in liters)}}$ was made = .04.

A double wood-fiber filter makes possible a very slow velocity of passage of the water to be filtered, and makes possible a washing of the filters one at a time, without interrupting the operation and with very small loss of water.

The old conical-shaped shallow filters were removed, as they were very quickly damaged, and usually did not permit a flow from both at once.

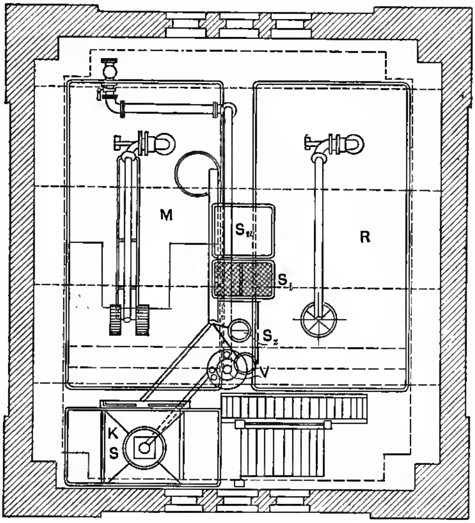

FIG. 119.

The filter spaces located in the lower part were used as clearing-chambers without any wood-fiber filling at all, and the time of passage of the water was thus increased

In Figs. 123 and 124 is shown a design for a water-purifying plant in which the two wooden tubs were to be used. The lime-distribution and the filter are sunk below the floor; the soda trough is placed above the platform; and the distributor is placed in a little dormer-house.

In Figs. 125 to 129 plants are shown which are operated entirely from below. Figs. 125 to 128 are clear without closer description; it will only be noted that in Fig. 125 the use of a wood-fiber filter is shown, while in Fig. 126 an automatic sand-filter is shown in use.

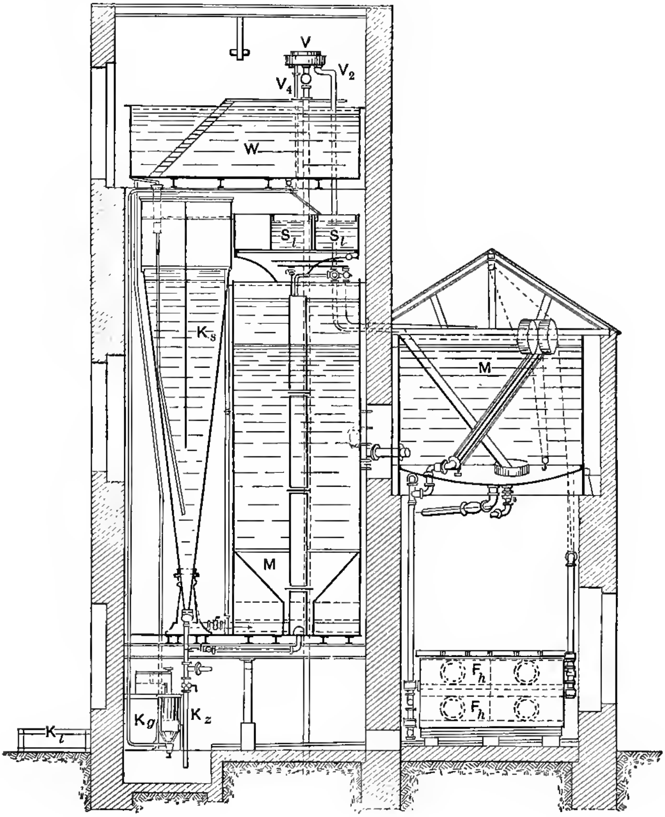

FIG. 120.

The starting of washing-out is effected by means of the connected valves. By turning the former, the outlet to the distributor is closed, and the water runs over the bent pipe into the vertical pipe, carrying air along with it, which, as in the Reisert filter roots up the sand without steam being necessary for doing this. As no stirring-arm can be arranged on the central pipe in this sand filter, there is, of course, no guarantee that the whole quantity of sand will be uniformly washed.

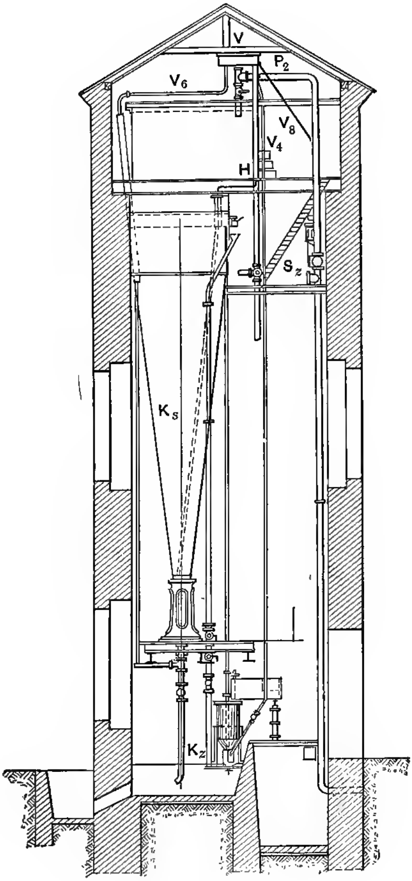

FIG. 121.

The following example is of value as giving the calculations for a water-purifying plant of this type with an hourly capacity of 1.5 c.m.

The water is well-water and contains:

Bound CO_2	$17.4° = a$
Calcium	$15.7° = b$
Magnesia	8.4°

and has a total hardness of $(CaO + MgO) = 24.1° = c$.

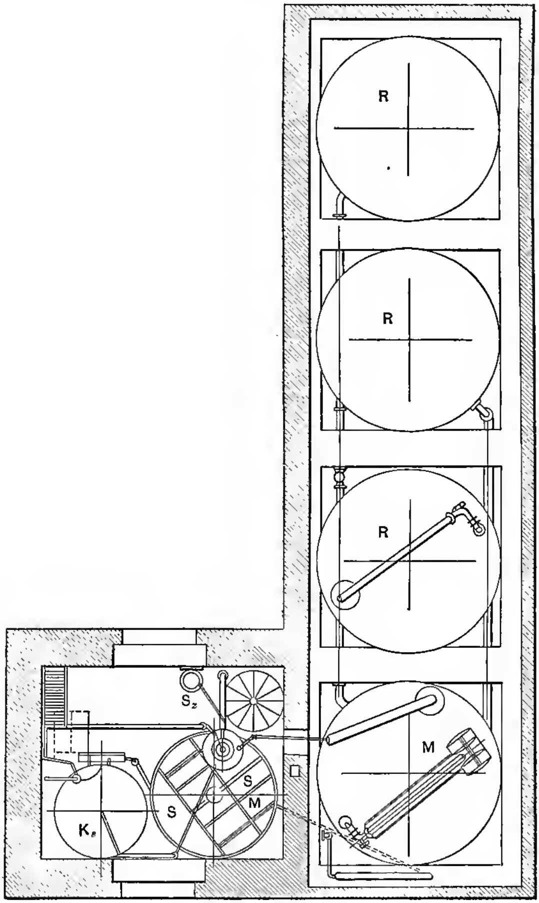

FIG. 122.

According to Kalmann, there is required for purification

$$2a - b = 19.1° \text{ CaO},$$

$$c - a = 6.7° \text{ caustic soda},$$

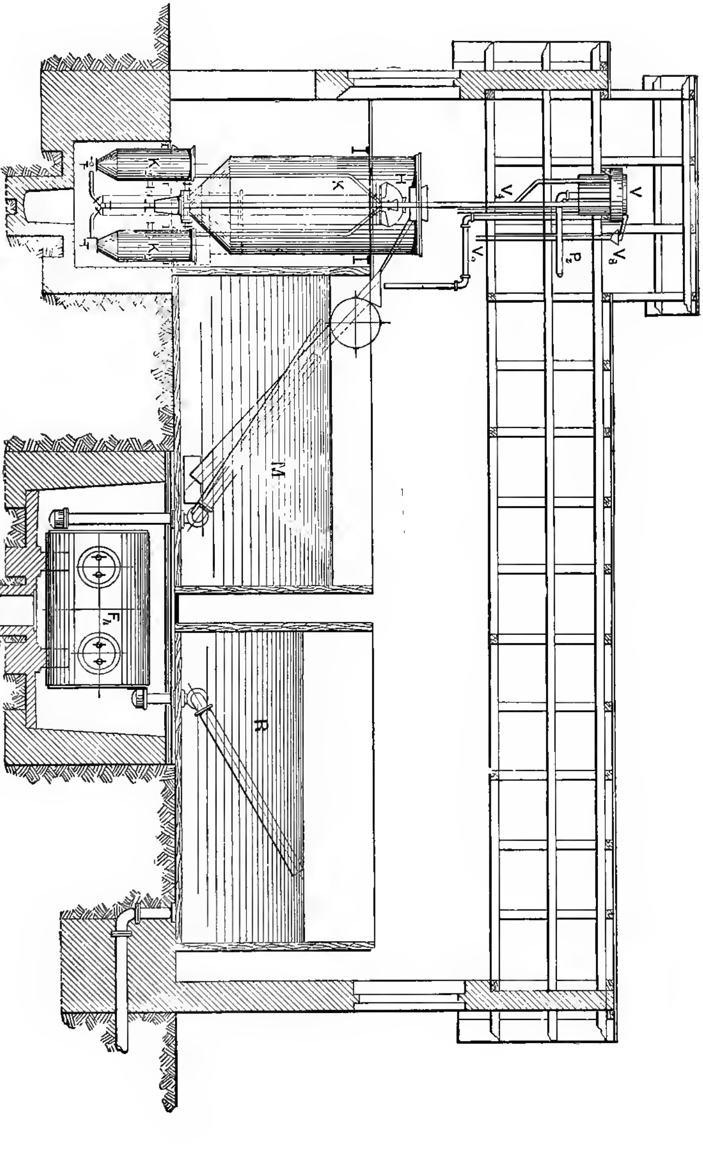

FIG. 123.

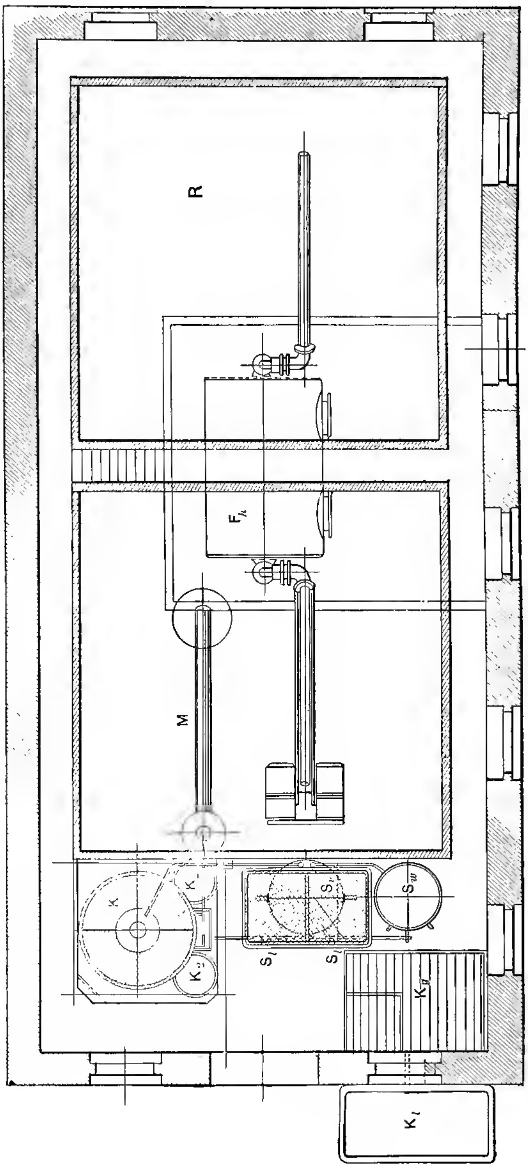

FIG. 124.

and if, instead of caustic soda, soda-ash is used, 25.8° CaO and 6.7° soda-ash.

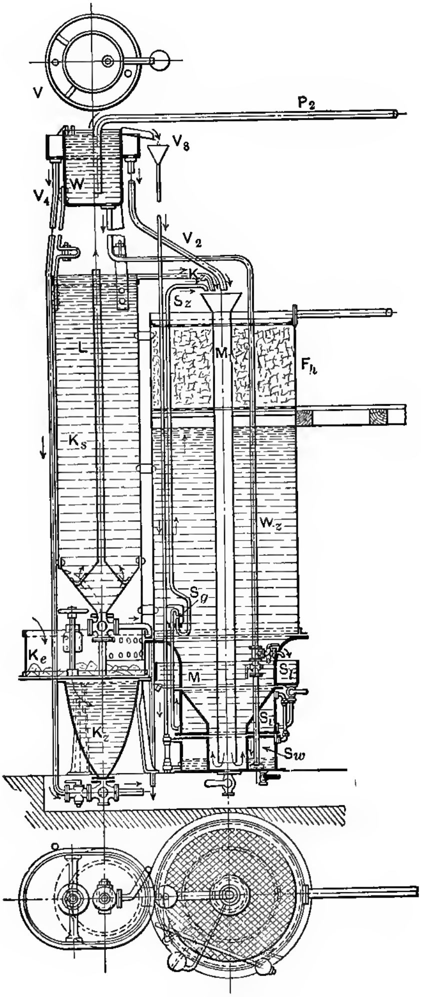

FIG. 125.

As it will be purified with lime-water of 120°, for 1 c.m. of raw water the proportion will be $120^\circ \times x = 25.8^\circ \times 1000$ liters. Therefore for one cubic meter of raw water $x = 215$ liters of lime water are necessary, which is about one fifth of the raw water

If it is assumed that for a day of ten hours a minimum quantity of 60 liters of soda-ash solution should be used, in order that the dimensions of the soda-ash vessel may not be too great and that the amount admitted may not be too small, we have the following figures:

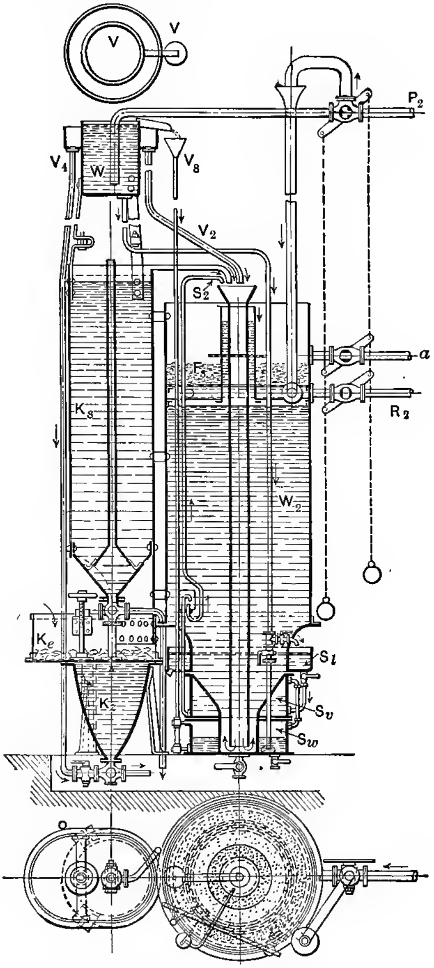

FIG. 126.

For 1 c.m. of raw water 6.7° soda-ash is necessary; with 1.5 c.m. as an hourly performance we use 15 c.m. per day; therefore

$$15{,}000 \times 6.7^\circ = 60 \text{ liters} \times y^\circ,$$
$$y^\circ = 1675^\circ.$$

Therefore we must have a soda solution of 1675° strength (and as we can make a soda solution up to 3600°, the previous condition is practicable).

For 1 c.m. of raw water there is necessary in soda-ash

$$1000 \text{ liters} \times 6.7^\circ = z \text{ liters} \times 1675^\circ.$$

$$z = \frac{4}{1000} = \frac{1}{250}, \text{ approximately.}$$

Consequently the divisions of the distributing weir are to be so divided that

$\frac{1}{5}$ of the length of the weir is for the lime-water.
$\frac{1}{250}$ “ “ “ “ “ “ “ “ “ soda-ash solution.

The distributor chamber, whose contents in water cause the compression of the air in the two air chambers, must have such a capacity that the soda-solution will pass from the uptake pipe to the outlet.

If we designate the volume of the

Distributor by		W
Air-regulator for water by		$S_w = 120$ liters
“ “ soda “ S_v	empty space	$S_v^l = 30$ “
	soda-ash space	$S_v^r = 60$ “
Soda-ash solution trough by		$S^1 = 60$ “

and if the pressure head for the soda-ash solution = 5 m. and the specific weight of the soda-ash solution of 1675° is the same as if 31.8 grams of 100% soda-ash (calcined or ammonia soda) were contained in one liter of water, then the height must be multiplied by 1.032, that is 5.160 meters.

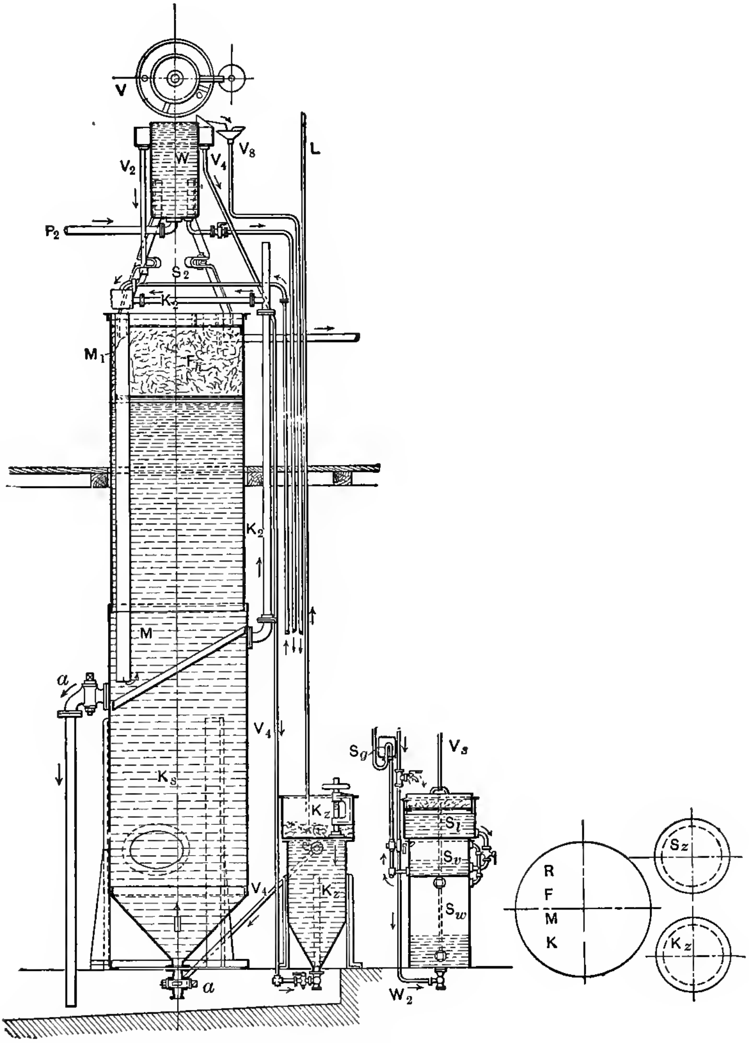
V
W
V_8
V_2
V_4
L
P_2
S_2
K
M_1
F_h
K_2
M
a
V_4
K_s
S_g
V_s
K_z
S_l
S_v
S_w
V_4
K_z
a
W_2
R
F
M
K
S_z
K_z

FIG. 127.

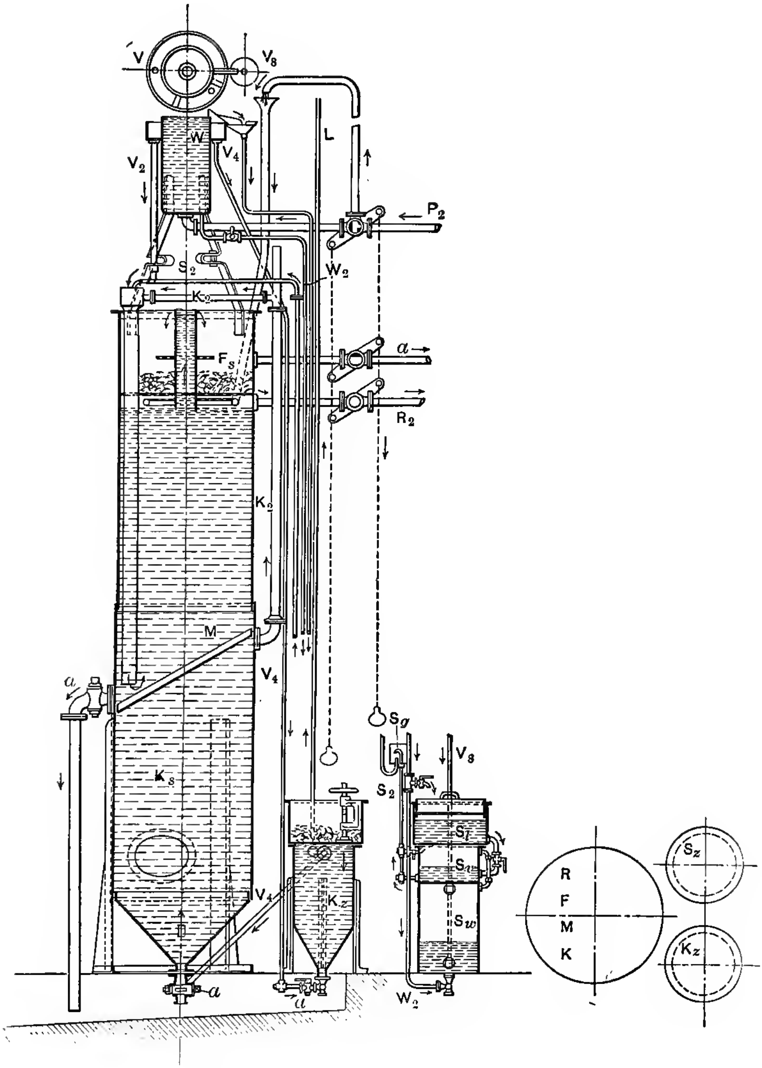
V
V₈
W
V₄
V₂
L
P₂
S₂
K₂
W₂
F₈
a
R₂
K₂
M
V₄
a
K₈
Sg
V₈
S₂
Sl
Sw
Sw
R
F
M
K
Sz
Kz
Kz
V₄
a
a
W₂

FIG. 128.

If we assume 5 m., the overflow of the soda-ash would not take place too early. If the volume of $S_w=120$ liters, $S_v=90$ liters, and assuming that 60 liters of soda-ash will be used in ten hours, there will be let down S_w^w liters of water into S_w, in order to compress the air in the two chambers S_w (empty) and S_v (containing 60 liters of soda-ash) to an over-pressure of .5 atmosphere. Therefore $S_1=S_v{}^r$, and we have the following equation:

$$(S_v^l+S_w^l)\left(1 \text{ atmosphere}+\frac{h^m}{10^m}\right)=(S_v^l+S_w^l+S_w^w)\ (1 \text{ atmosphere})^{*}$$

$$S_w=S_w^w+S_w^l.$$

h = pressure head for the soda-ash solution (see Fig. 39).

For the previous case, inserting the values, we have

$$(30 \text{ liters}+S_w^l)\times 1.5=(30 \text{ liters}+S_w^l+S_w^w)\times 1,$$

$$S_w^w+S_w^l=120 \text{ liters},$$

$$(30 \text{ liters}+S_w{}')\times 1.5=150 \text{ liters},$$

$$S_w^l=70 \text{ liters};\quad S_w^w=\ 50 \text{ liters}=W.$$

The distributor chamber must therefore contain 50 liters. If the diameter of the edge of the distributor is 300 mm. we have for the height (h) of the water flowing over the same the following equation:

Quantity per sec. in cu. m. $=2/3\mu bh\sqrt{2gh}=$

$$Q=.000416 \text{ c.m. per sec.}$$

$$2/3\mu=.57,\quad h=.942 \text{ (circle of 300 mm. diameter)},$$

$$h'=\sqrt[3]{\frac{Q^2}{.57^2\times(.942)^2\times 2g}}=2 \text{ mm}.$$

---

[*] S = volume of soda-ash solution in the solution-trough. S_v^r is the same quantity of soda-ash let down. S_v^l is the air-space (uncompressed). $S_v^l+S_v^r=S_v$. S_w^w is the water let down to compress the air. S_w^l is the permanent uncompressed air in the vessel S_w; $\therefore S_w^l+S_w^w=S_w$.

If the diameter of the distributor chamber = 280 mm., the depth of the same would be found from the equation

$$50 \text{ liters} = F \times h',$$

where $F = 6.15$ square decimeters.

Distance from upper surface to the bottom

$$50 \text{ liters} = 6.15\ h',$$
$$h' = 810 \text{ mm.}$$

The velocity of the water in the vessel for mixing the raw water at 1.5 cu. m. per hour with the additions is given by the following:

If the diameter of the mixing- and clearing-vessel = 1200 mm., the area (deducting the area of the mixing-pipe) = 112.966 square decimeters; the quantity of water passing through = .416 liter per second, and therefore the velocity of the water is

$$.416 \div 113 = .0036 \text{ m.} = .4 \text{ mm. per second.}$$

If the diameter of the lime-saturating vessel = 680 mm., the area of the same is 36.16 square decimeters, and as the quantity of water passing through is .083 liter per second ($= 1/5 \times .416$), the velocity of the water is

$$8300 \times 3616 = .02 \text{ mm. per second.}$$

The quantity of water passing through the discharge-pipe V_4 (to the lime saturator) = .083 liter per second, and this must carry air along with it. The velocity of rising air $v = 2.2$ decimeters per second; therefore the velocity of the water must be greater than 2.2 decimeters in order to carry the air downward. We may assume the area of the pipe to be half as large as the area calculated to give the velocity $v = 2.2$ decimeters.

Area of the pipe $F = \frac{1}{2}\frac{Q}{v} = \frac{1}{2} \times \frac{.08}{2.2} = .018$ decimeter.

Diameter of the pipe 16 mm.

The diameter of the downtake pipe for the raw water entering for purification (which carries no air with it) may not be too small or the annular space of the distributor will overflow. It may be assumed as being 50 mm.

A minimum area is advisable for the water-inlet pipe to the soda-ash distributor, or else by not completely compressing the air in the air-chamber the supplying of soda-ash will begin too late.

Cost of Operating.

It would require: 25.8° CaO; 6.7° soda-ash per 1 day = 10 hours $= 10 \times 1.5$ cu. m. = 15 cu. m. of water.

As this water required .258 gram of burnt CaO per liter, we have a daily requirement for 15 cu. m. $\times$ .258 kg. = 3.87 kg. of CaO.

As 1 kg. of burnt lime in a thick mixed condition makes about 4 liters and in thin paste about 10 liters, the lime-distributor must at least contain $10 \times 3.87 = 39$ liters.

Therefore K_2 and K_3 must at least contain 40 liters.

In order to calculate how large the surface for spreading out the soda-ash must be, the daily quantity of soda-ash necessary must be determined, as the soda-ash must be distributed evenly (for the sake of a uniform soda-ash solution).

As 6.7° of soda-ash are necessary there are required:

For 1 liter .067 gramm of soda-ash calculated as CaO;
" 1 " $.067 \times \frac{53}{26}$ grams soda-ash of 100% strength;
" 1 " .127 gram of soda-ash of 100% purity;
" 1 " .134 " " " " 94.78% purity.

The .134 gram is approximately double the amount calculated above in terms of CaO. Hereafter we will use 95% soda-ash and multiply the soda-ash calculated as CaO by 2 for the weight of soda-ash required.

If 1 liter of calcined or ammonia soda-ash weighs 1.5 kg. the area of the soda-tank and the depth of the latter may be easily calculated. The layer of soda-ash may not be made higher than about 15 mm. or else the solution will not take place under three hours.

In the previous case 15000 liters×.134° of 95% soda-ash is used; that is, 2000° = 2 kg.

The 2 kg. placed on the sieve will make a depth of

$$h = \frac{2 \text{ kg.}}{\text{sp. g.} \times F}.$$

F = the area of the sieve = 56.52 square decimeters,

$$h = \frac{2}{1.5 \times 56.52} = .023 \text{ decimeter} = 2.3 \text{ millimeters},$$

which will be the depth of the layer of soda-ash on the sieve of the soda-ash trough.

As 1 kg. of lime costs $1^4/_{10}$ cents and 1 kg. of soda-ash costs 4 cents the daily cost amounts to

$1.4 \times 3.87 =$ 5.4 cents for lime
$4. \times 2.0 =$ 8. " " soda-ash

Total daily cost 13.4, or 13.5 cents.)

The duration of the purifying processes:

(*a*) The passage of the water through the clearing vessel, which has an approximate volume of 2400 liters, amounts to $\frac{V}{.416} = \frac{2400000}{416} = 5769$ seconds = 1 hour, 36 minutes, 7 seconds.

(*b*) The passage of the water through the lime-saturator, which has an approximate volume of 908 liters, amounts to $\frac{908}{.083} = \frac{908000}{83} = 10939$ seconds = 3 hours, 2 minutes, 19 seconds.

In case the ground space at disposal is very small and the height is so great that the distributor is located in the dormer, the type of plants shown in Figs. 127 and 128 recommends itself. With regard to the filters the statements concerning Figs. 125 and 126 are of value.

In Fig. 129 is shown a small railway water-station, in which a steam-boiler is located and in which by dividing the over-

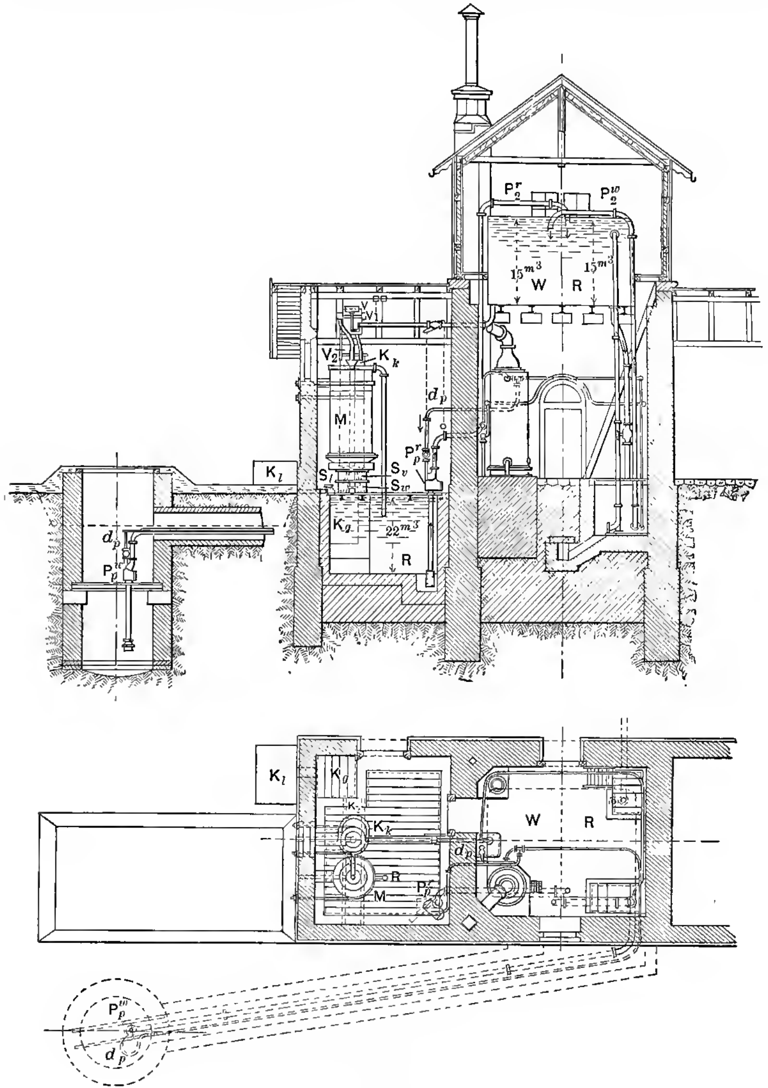

Fig. 129.

head reservoirs into two spaces the construction of a water-purifying plant similar to Figs. 125 and 126 was effected, and by the installation of a pure-water cistern with an ejector and the necessary piping a cheap and mechanical water-purifying plant was obtained.

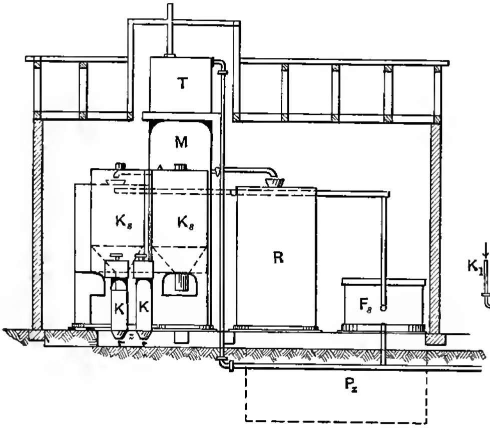

FIG. 130.

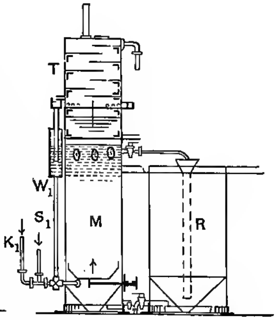

FIG. 131.

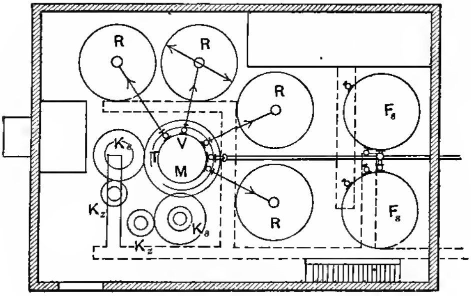

FIG. 132.

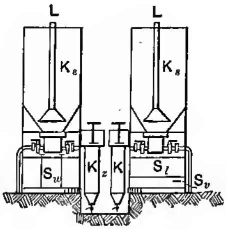

FIG. 133.

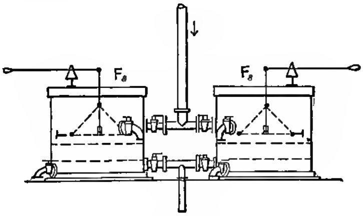

FIG. 134.

Figs. 130 and 131 show the designs of a water-purifying plant for a manufacturing plant in which the preheating of the water is taken into consideration.

In this arrangement there are two closed lime distributors K_zK_z, two alternately operating lime-saturating tanks, and four pure-water vessels, in each of which one fourth of the total amount of water to be purified enters and the mixed water therefore rises very slowly, and lastly two sand-filters whose washing out is effected by moving perforated screens up and down while a stream of raw water enters from below.

By means of these mechanical devices the sand over the whole area is placed in motion, for which reason the washing is very complete. The soda-ash distribution is accomplished by means of the air-chamber system.

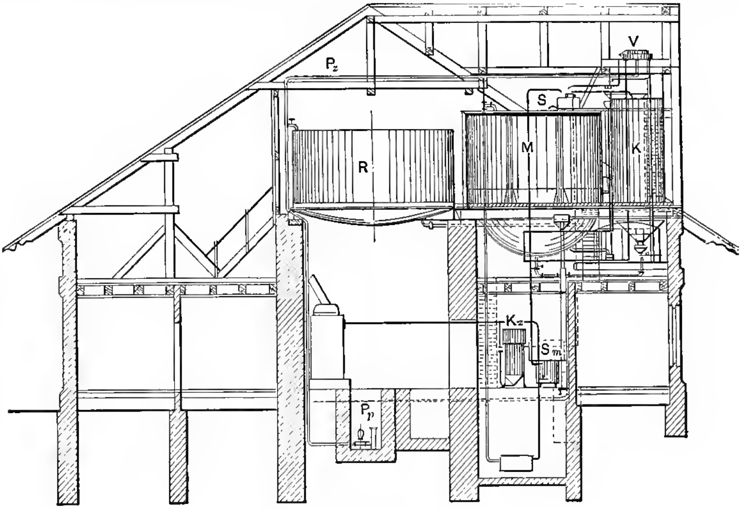

Fig. 135.

Figs. 135 and 136 show a water-purifying plant for a water-station at which an increase in discharge (from 8 c.m. per hour to 20 c.m. per hour) must be taken into consideration. The building must remain undisturbed and an outhouse to the roof was only considered permissible. This construction of the roof made it possible to place a new mixing and pure-water reservoir below the lime-saturating vessel *K* and the distributor *V*.

The lime and soda-ash distributor were placed below on the ground floor. Later the air-chamber system was contemplated.

The old raw-water reservoir served for a pure-water reservoir. The new reservoir was very broad and made with a half-round bottom. On this account a very small velocity of the rising current was made possible. The quotient $\frac{K^k}{M^l}=.1$; therefore the construction was a very economical one.

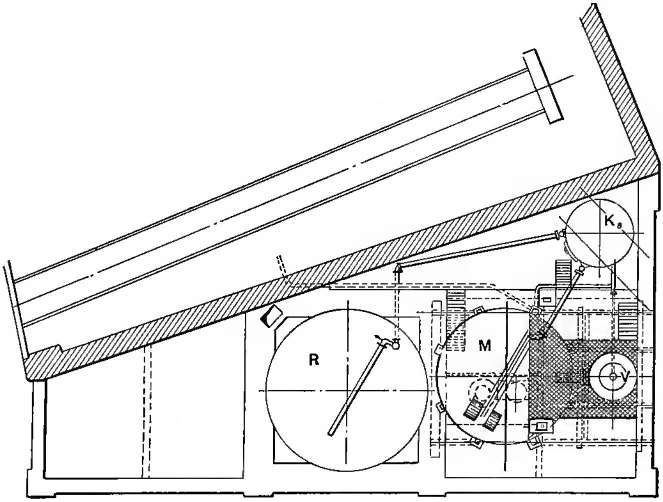

Fig. 136.

Two pumps and a cistern were on hand in a pumping-plant placed at a distance from the railway water-station (see Figs. 137 and 138). The water is forced from one pump into the station located higher up, while the second pump is a reserve pump.

The changing of the water-purifying plant into a pressure system requires an addition to the building in which M, F, V, K_z, and S_z are located. Moreover the construction of a cistern for the pure water is necessary. The water will be purified with lime and soda-ash according to Case 1. The operation takes place as follows: The water is forced by a pump into M

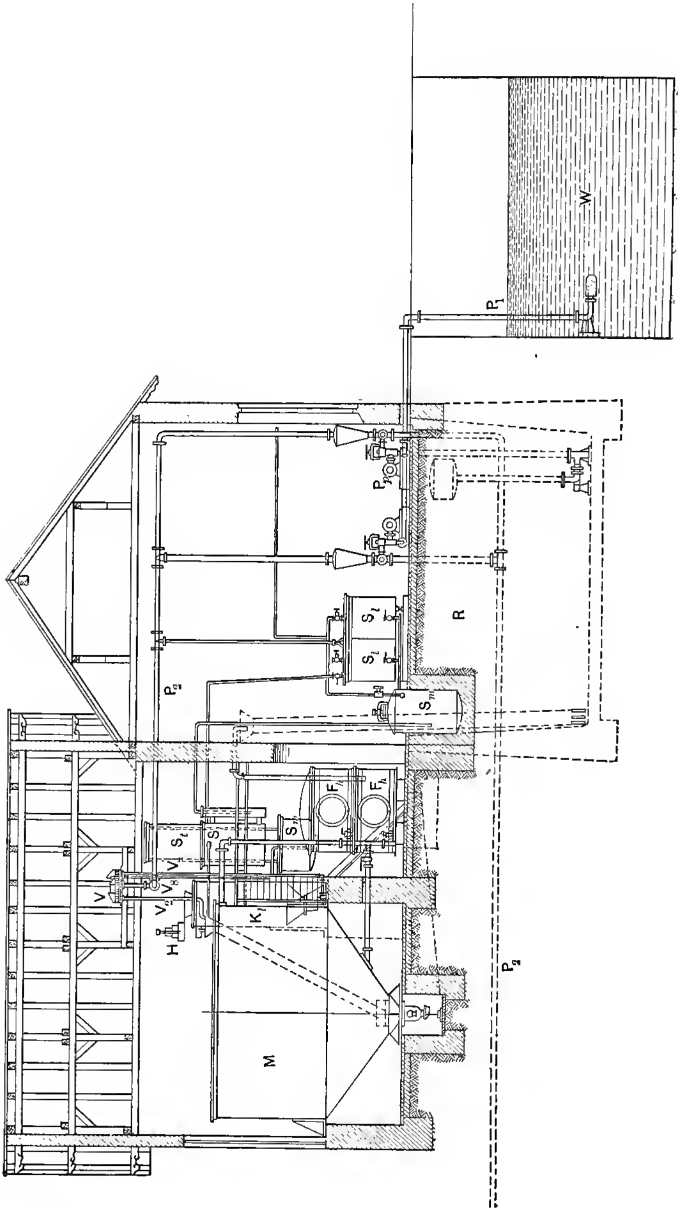

FIG. 137.

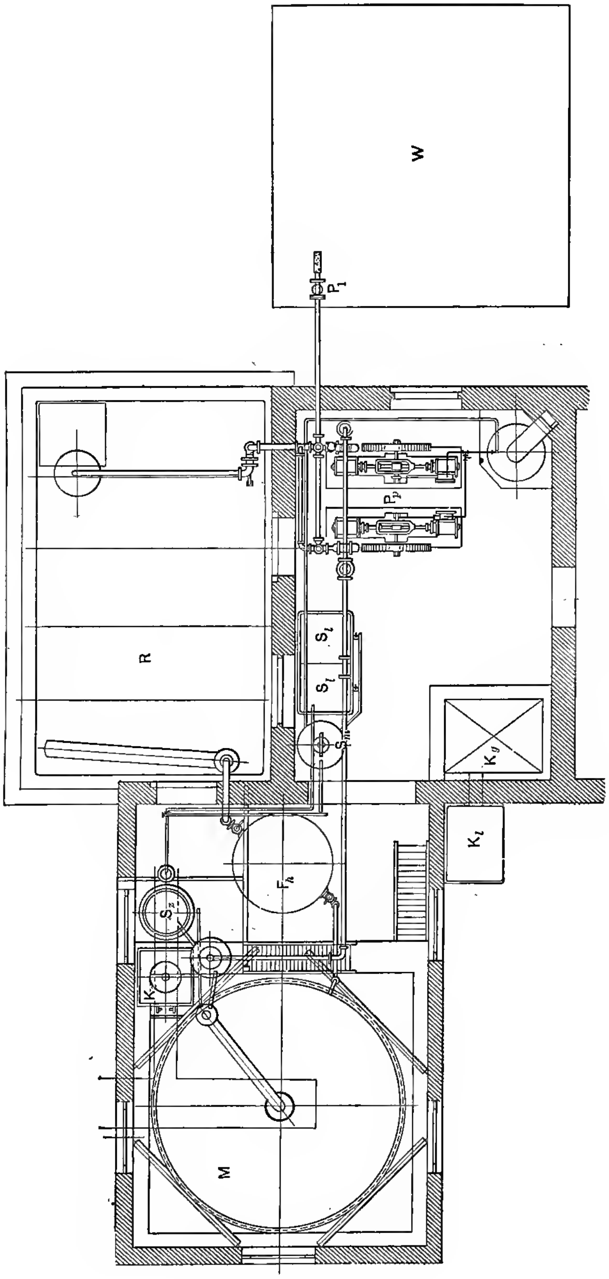

FIG. 138.

and mixed with the reagents. The preparation of the reagents takes place in the soda-trough S_e placed in the old building and the soda-ash is raised by an air-pump operated by steam from the boiler of the plant. Here it is very important to make the reservoirs *M* and *K* very large so that no incrustation forms in the pipes carrying the water to the point of delivery.

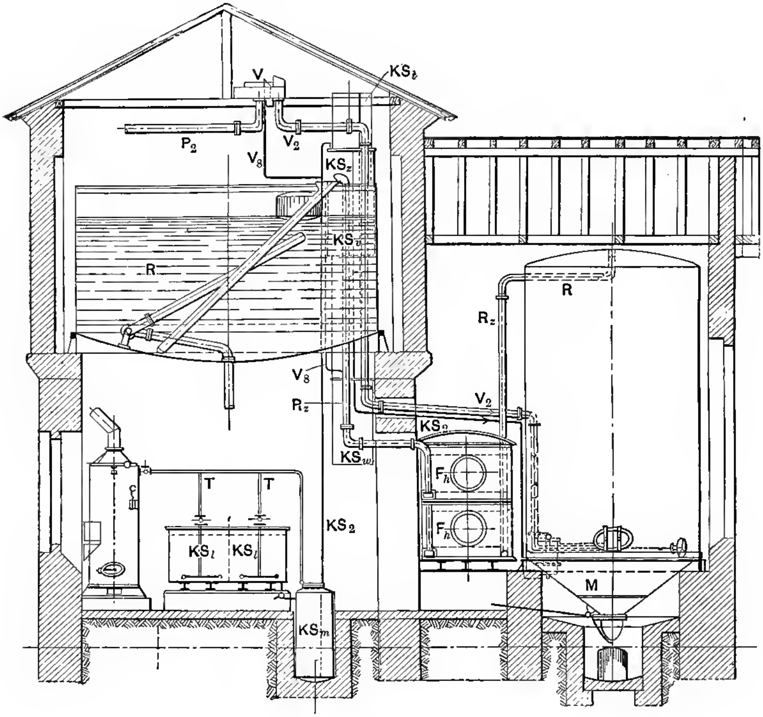

Fig. 139.

A decanting pipe will therefore be used for drawing off the water, which takes the water from the top surface and therefore allows it to be in the reservoir the longest possible time.

Figs. 139 and 140 show a water-purifying plant for a railway water-station in which the water is purified according to Case 2 (page 46), the mixing-chamber is closed, and the pure water is stored in the reservoir.

The mixing of the raw water with the reagents takes place under the whole pressure of the head of water from the ground to the top of the pure-water reservoirs placed overhead. Therefore an especially good precipitation of the impurities and an excellent clarification may be expected. The clearing will also be very much assisted by the large area of the closed vessels.

The caustic soda solution formed from lime and soda-ash while heated will be admitted into an air-pump and raised by steam as shown in Fig. 36, page 109, into the caustic soda distributor.

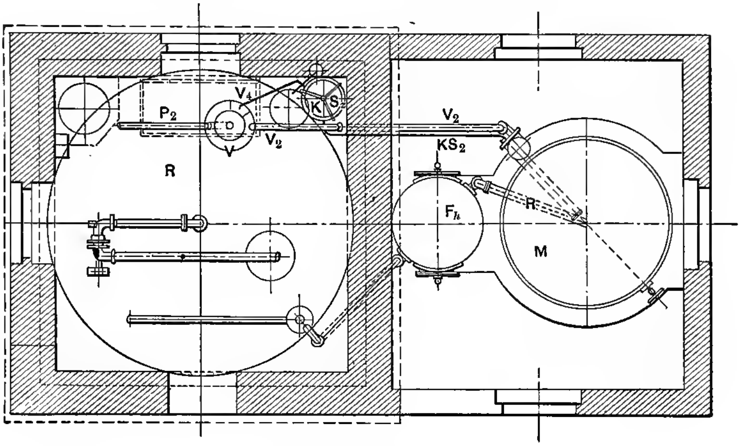

Fig. 140.

Figs. 141 and 142 show another solution of the problem just mentioned. *R* is the old resevoir, *M* is the mixing-reservoir which was placed in an annex.

In the same annex *V*, *S*, and *F* are placed. As, according to Case 2, caustic soda must be used, and as the latter may be most cheaply produced from lime and soda-ash, for which the heating of the soda-ash solution is necessary, the installation of a heating-oven W_t was made.

The distribution of the caustic soda is effected by the air-chamber system.

If the water must be purified according to Case 3 (page 46)

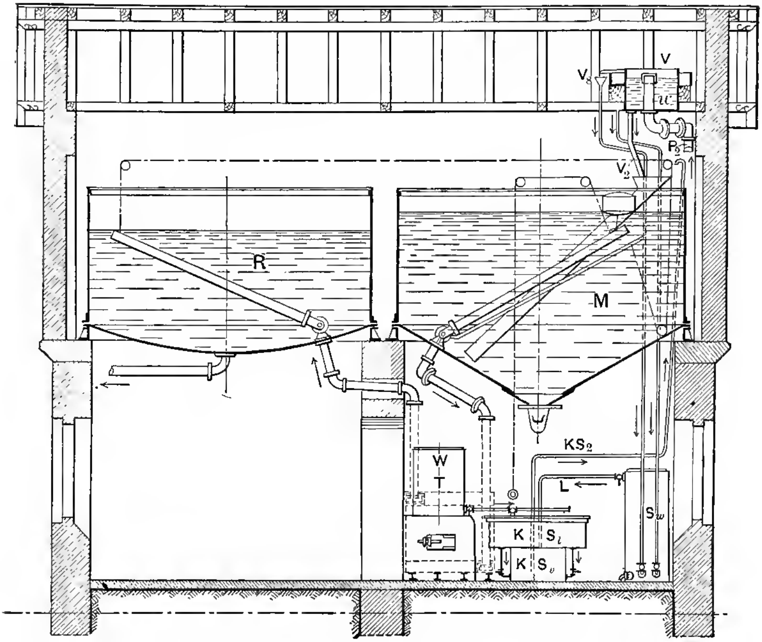

FIG. 141.

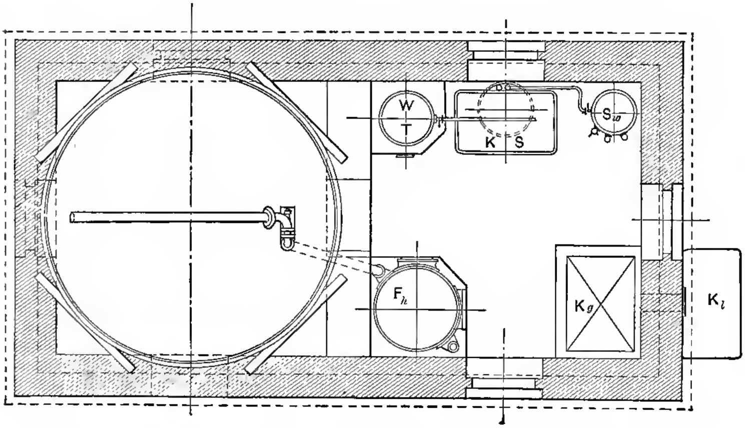

FIG. 142.

with caustic soda and soda-ash, then besides the vessels K, S_l, S_w, KS_v, similarly formed vessels S_l, S_w, S^v must be erected.

The quotient of $\frac{K}{M}$ will be very small, therefore the construction is a very economical one.

When a water must be purified, according to Case 3, with caustic soda and soda-ash, plants similar to the two following must be used for small railway water-stations.

In the plant shown in Fig. 143, the water is forced by means of a pulsometer into the distributor, from which it flows to the mixing-pipe M_l and to both of the air-chambers KS_w and S_w.

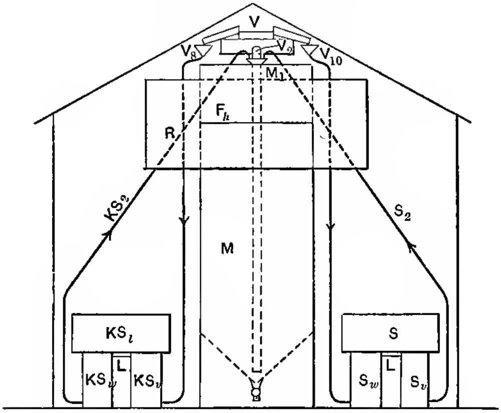

FIG. 143.

The quantity of water flowing through the pipes V_8 and V_{10} displaces a similar quantity of caustic soda and soda-ash which flows out through the pipes KS_2 and S_2 and becomes mixed in the pipe M_l with the raw water. In the upper part of the clearing-chamber, which must correspond in height and width to the water pumped per second, is the wood-fiber filter.

In the plant in Fig. 144 the raw water is forced through the pipe P_2 into the division of the overhead reservoir and flows out of the latter into the pressure regulator and out of this over a straight weir distributor to M_l, KS_w, and S_w.

In both air-chambers the water rises steadily and compresses the air within them and the air in the neighboring air-chambers containing caustic soda and soda-ash and raises an equal quantity of the chemicals to the place where mixing takes place. In the chamber M the water thus treated clears itself and passes through the filter to the pure-water cistern placed on the ground level. From this the pure water will be raised into the pure-water division of the overhead reservoir and flow from there to the point of delivery to the locomotives.

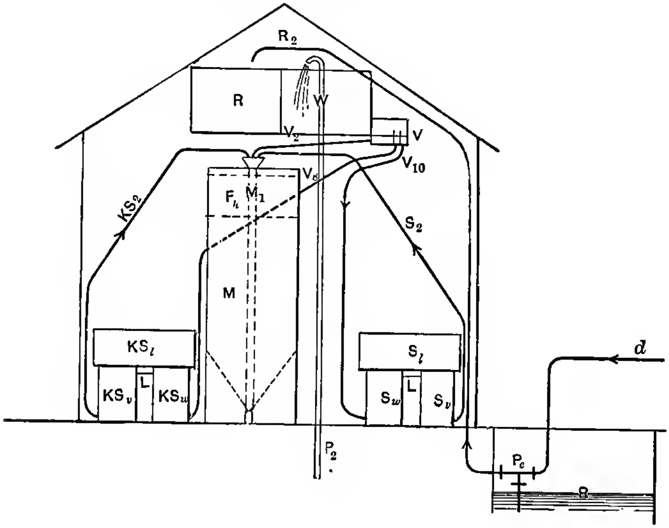

FIG. 144.

While in the plant shown in Fig. 143 a very spacious mixing- and clearing-vessel is used, if a pulsometer is used, this chamber may be made smaller as in Fig. 144, because the water flows slowly from the reservoir W through the pressure regulator D_w and over the edge of the distributor through the pipes V_2, V_8, and V_{10}.

In the following Figs. 145 to 158 are shown the intermittent system of water-purifying plants for railway water-stations, in which the water is pumped from a steam-plant located lower down and forced from that to the top of the reservoir.

The performance amounts to 36 cu. m. per hour and the purification takes place according to Case 1. The smaller overhead reservoirs are old. The wing building contains the larger new reservoirs and the rest of the apparatus.

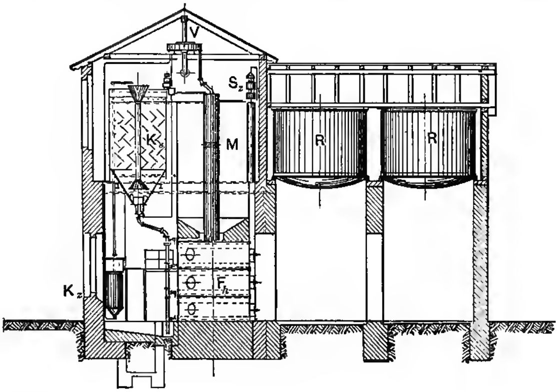

FIG. 145.

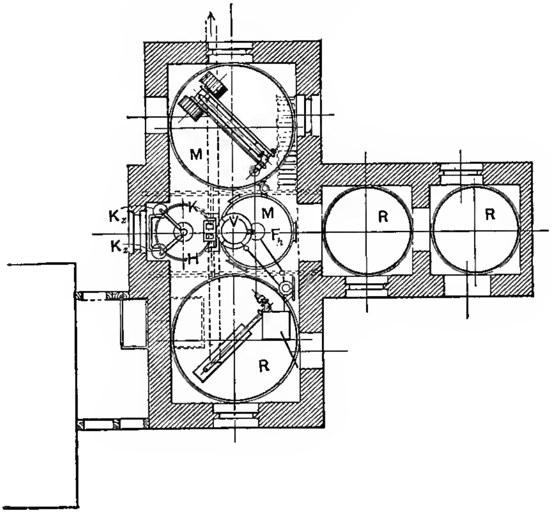

FIG. 146.

The plants shown in Figs. 145 to 148 consist of the distributor *V*, the elevated lime saturators with clarification taking place alternately, the first mixing-chamber placed between the large elevated reservoirs, the wood-fiber filters in

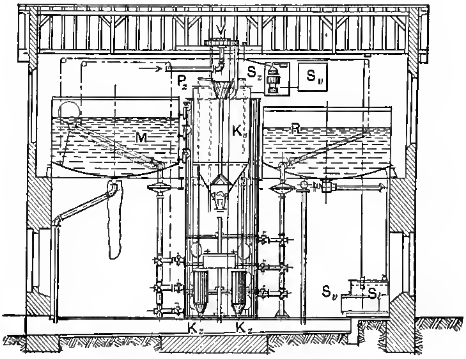

FIG. 147.

three parts placed one above the other, the lime distributor on the ground floor, and the soda-distributor placed above

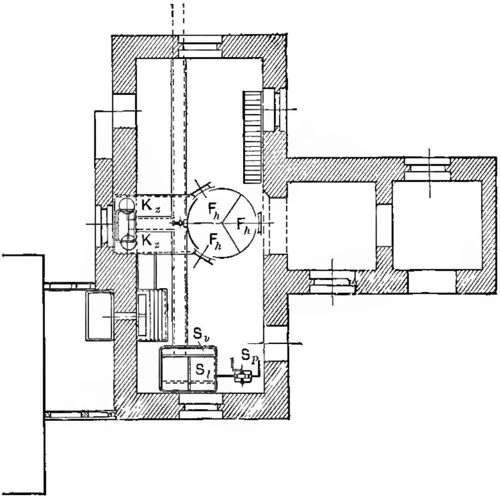

FIG. 148.

the reservoirs, into which the soda-ash solution is lifted by a hand-pump and the arrangement of the pressure pipes.

One of the elevated reservoirs serves as a second mixing- and clearing-chamber. The latter is also shown with a funnel-shaped bottom on account of the easier removal of the precipitates.

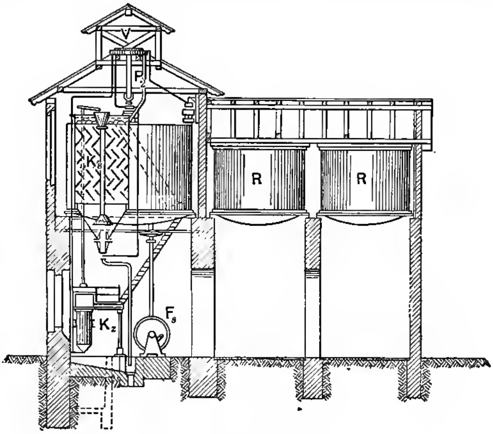

FIG. 149.

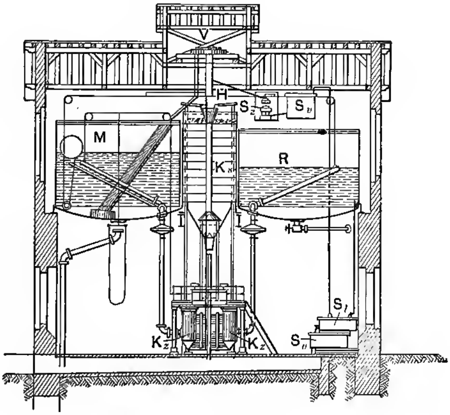

FIG. 150.

The filters are divided into three parts so that the fiber can be changed without interrupting the operation.

The entire manipulation takes place from the ground floor.

The quotient $\frac{K \text{ (in kroners)}}{M \text{ (in liters)}}$ is very small, because pure water may be drawn from both elevated reservoirs, and is .15.

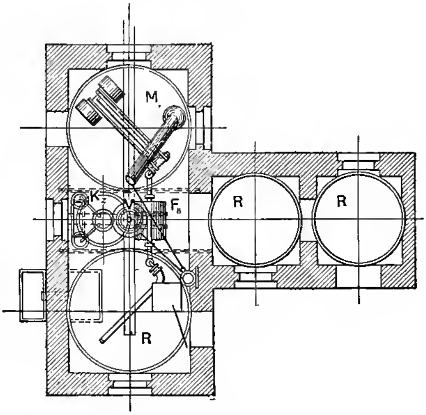

FIG. 151.

In Figs. 149 to 152 the first mixing-chamber is dispensed with. The mixing takes place in one of the new elevated reservoirs, the latter being placed higher than the old elevated reservoirs, so that a sufficient overpressure is produced for the Kröhnke sand filter used.

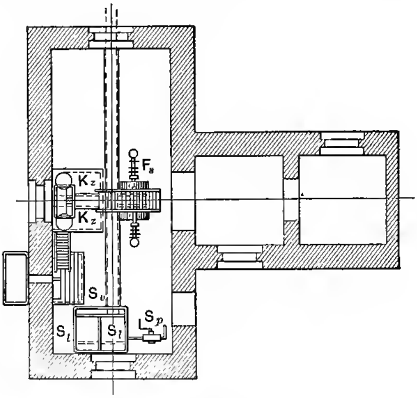

FIG. 152.

The soda-ash distribution is effected as in Figs. 145 to 148. In Figs. 153 to 156 all four elevated reservoirs are used

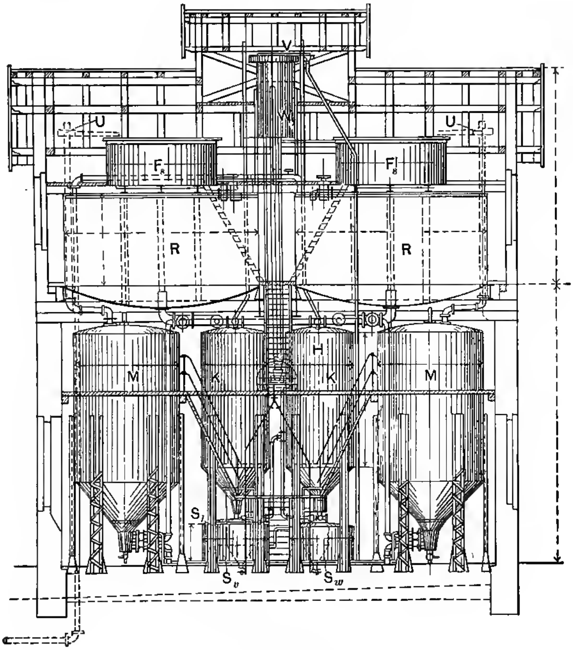

FIG. 153.

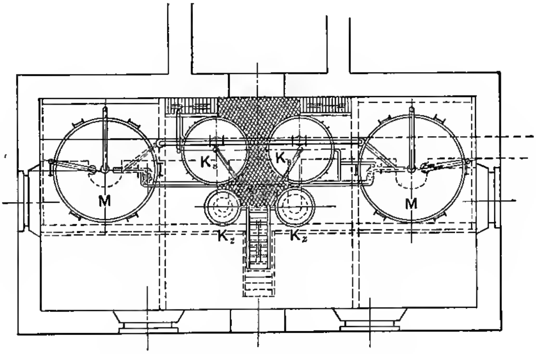

FIG. 154.

as pure-water chambers and the mixing of the water with the reagents is effected in two closed mixing-tanks *MM* arranged

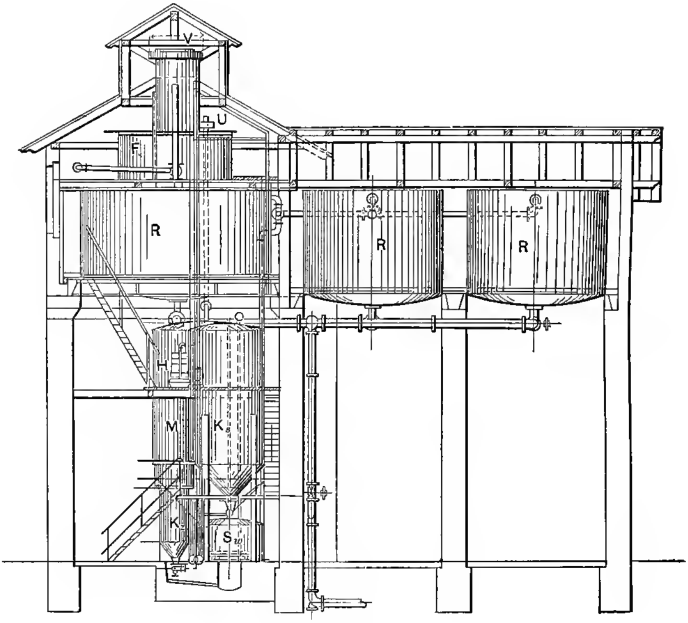

FIG. 155.

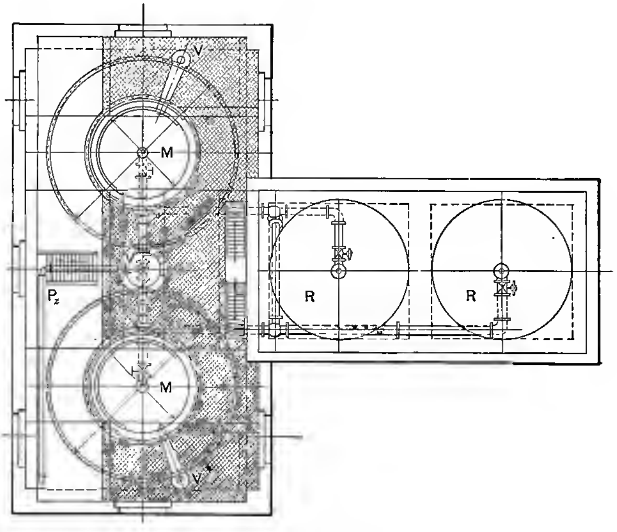

FIG. 156.

under the former. In like manner the lime is placed in two closed vessels below these and the water admitted alternately to one or the other lime saturator.

The soda-ash distribution is effected by the air-chamber system. The air-chambers and the soda-ash trough are arranged below the lime saturators.

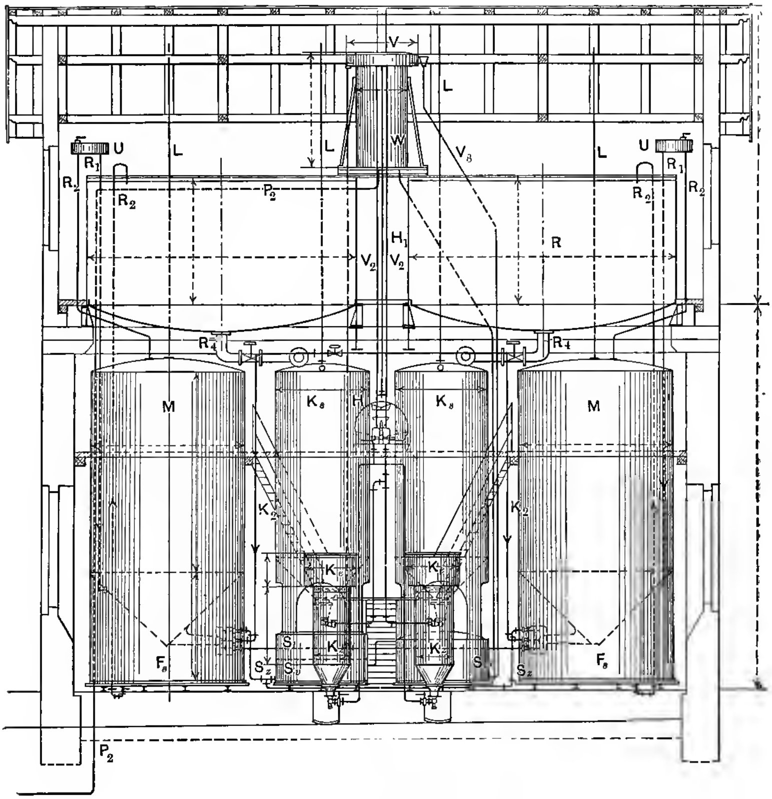

FIG. 157.

The lime distribution is likewise operated alternately. The filters are sand filters and are located above the elevated reservoirs. They are washed out by means of mechanical stirring devices with a stream of water from below.

On account of the construction the water rises uniformly in both closed mixing-chambers and the overflow to the filters is achieved.

In Figs. 157 and 158 the filters are placed in the lower part of the mixing-chambers, and these may be sand filters (as shown) or wood-fiber filters.

The washing out of the filters may take place where sand is used without steam by means of a stream of water carrying air with it. This will not stir up the whole area of the sand, depending on the design so uniformly as if a mechanical stirring took place, yet the action is not as bad as with the Reisert filter. If we would improve this action, we must bring the pipe for the inlet of the water, to be mixed in the mixing-chamber, to the lowest point of the latter and use a stirring-arm in the filter.

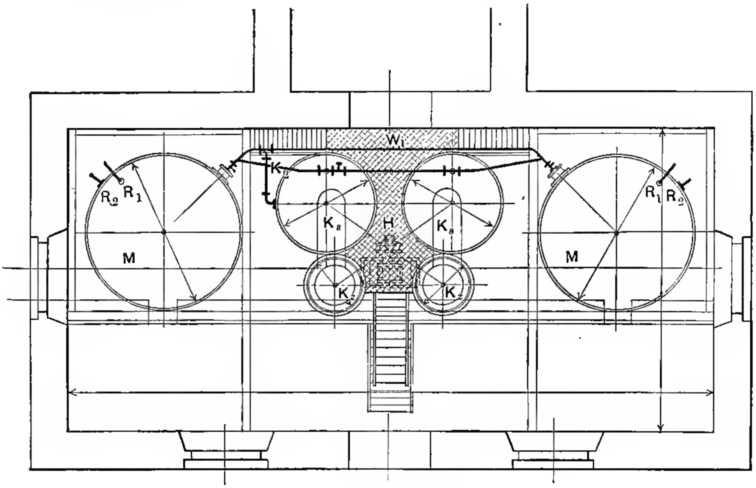

FIG. 158.

In Fig. 159 is shown a plant in which decanting-pipes were used on account of decreasing the quotient $\frac{K}{M}$. The soda-ash distributing-tanks are separated from the lime-saturator. The wood-fiber filters are cylindrical.

The lime-saturator was placed on iron beams, which were

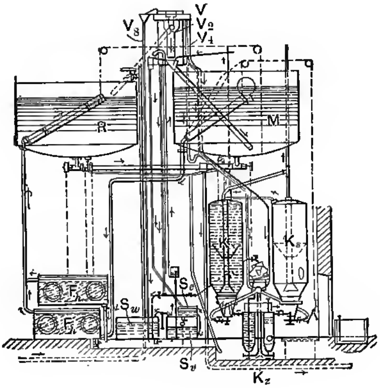

FIG. 159.

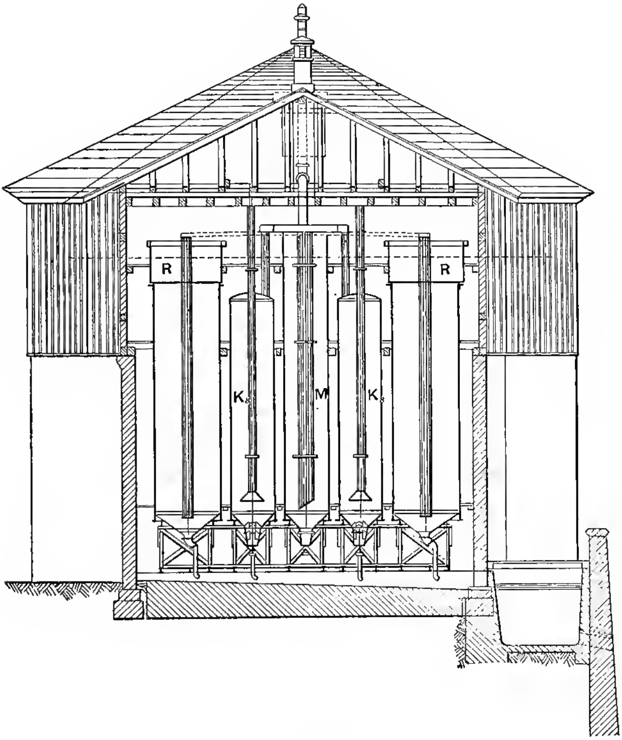

FIG. 160.

supported on columns. In this plant the tanks could be arranged separately or grouped as desired, which form of installation adapts itself to the space at a factory which would not permit of an assemblage of all the separate parts in one place on account of want of space or on account of the size.

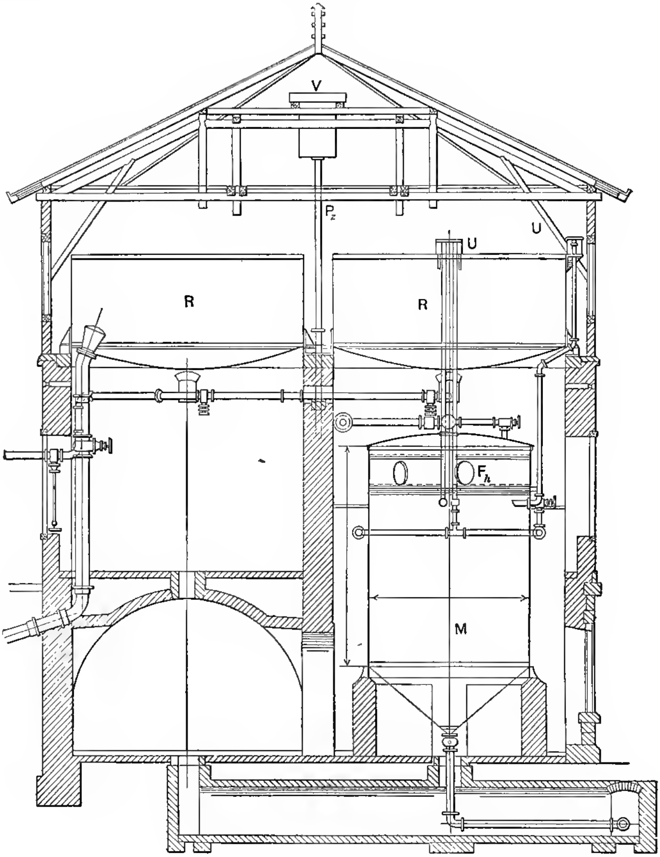

Fig. 161.

In Figs. 160 to 168 is shown the reconstruction of a water-purifying plant of the Berenger system.

From the ground plan of Fig. 162 it may be seen how the five high Berenger mixing- and clearing-tanks are placed in the fore part of the octagonal water-station building.

In case the condition of the latter permits a wider application, the middle one of these Berenger tanks will be used as a mixing cylinder, the ones next to it as lime-saturators, and the outside ones as clearing-chambers. Under one of the elevated reservoirs present and below the opening of the present arches would be erected a high mixing-chamber closed on top, in whose uppermost part a wood-fiber filter divided in four parts would be built.

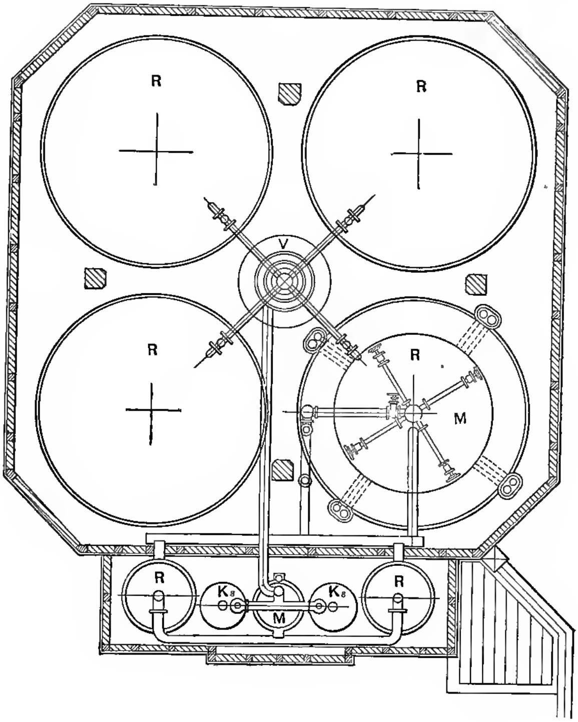

Fig. 162.

In order to have the whole area of this mixing-chamber effective and to have the velocity of the rising current practically equal over the whole area, four overflow pipes (see Fig. 161) capable of being regulated must be used. The liquids overflowing from the same enter each of the four divisions of the filter, from which they then flow through a pipe connected to the topmost point of the filter into the four large pure-water chambers. By means of the installation of the overflow-pipes the quantity of water flowing through may be sufficiently equalized and the velocity of the rising current will be made as uniform as possible over the whole area of the clearing-chamber.

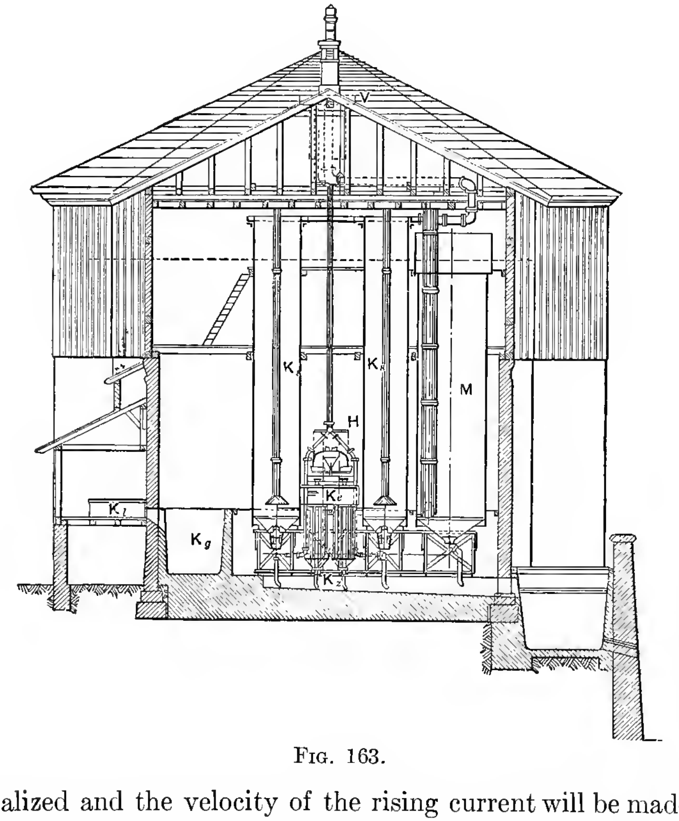

FIG. 163.

In the three remaining rooms under the elevated reservoirs would be located the steam-pump together with the stores of coal, lime, and soda-ash, while one of these rooms must be reserved for the installation of the lime and soda-ash distributing devices.

According to Figs. 163 and 164, in which only three Berenger tanks are used, the lime-distributing chambers are placed in the place of the middle mixing-chamber. The left-hand clearing-cylinder is dispensed with and the lime-pit is put in its place.

In the first type the lime-saturators are lengthened above in order to obtain the proper fall and are open; in the latter type they are closed and shown with communicating uptake pipes.

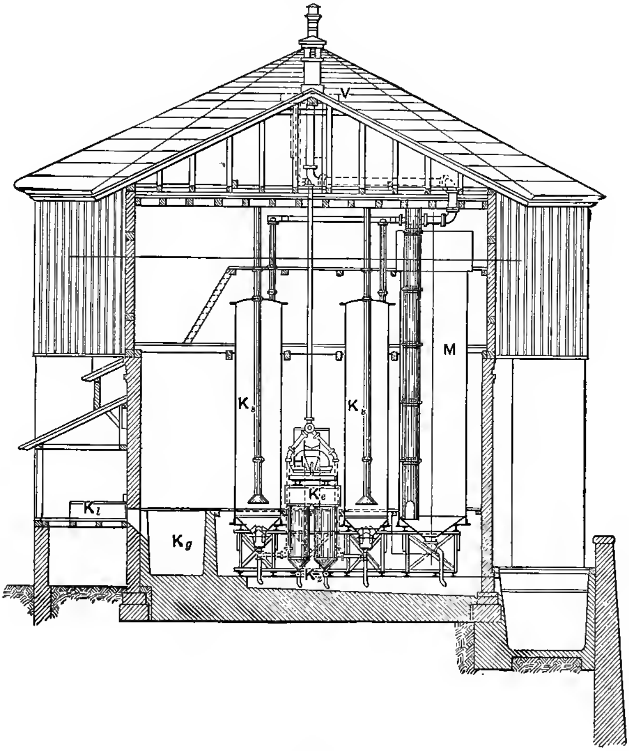

Fig. 164.

In Figs. 165, 166, and 167 the problem of reconstruction is so solved that, as in the previous cases, the soda-ash distribution takes place in one of the four rooms under the overhead reservoirs, that the lime-distributor will be arranged behind the two lime-

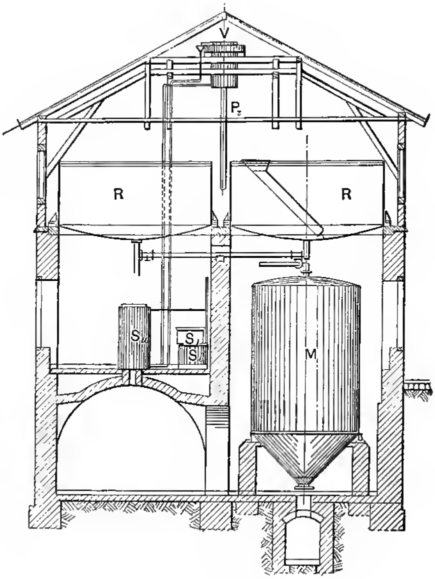

Fig. 165.

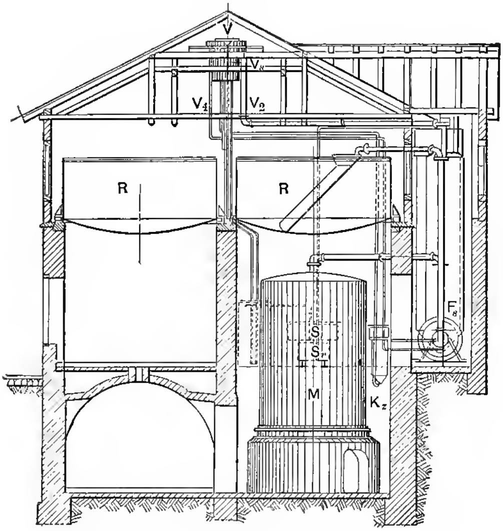

Fig. 166.

saturators, and that a closed Kröhnke filter will be used. When the latter can be placed on top, it may be a Kröhnke periphery filter. In order to obtain the higher pressure for the Kröhnke filter the lime and soda-ash chambers must both be correspondingly elevated or arranged to be closed.

One such closed arrangement is shown in Figs. 157 and 158. In all cases the lime-saturator will be operated alternately by means of a tilting vessel and the air-chamber system will be used for the soda distribution, as only by these means is it possible to have the preparation of the soda-ash take place on the ground and elevate it to the distributor.

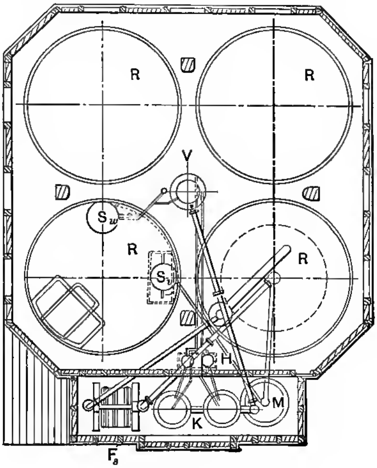

FIG. 167.

In railway water-stations for which the water is taken from a river, it often occurs that a passage leading to the cistern exists whose area is too small to be used as a gravel filter.

Fig. 168 shows how a sand filter can be built in this passage without great expense. It is accomplished by building in a transverse wall putting in cross-beams for supporting the perforated plates and the installation of the required pipes and valves, which make it possible to direct the passage of the

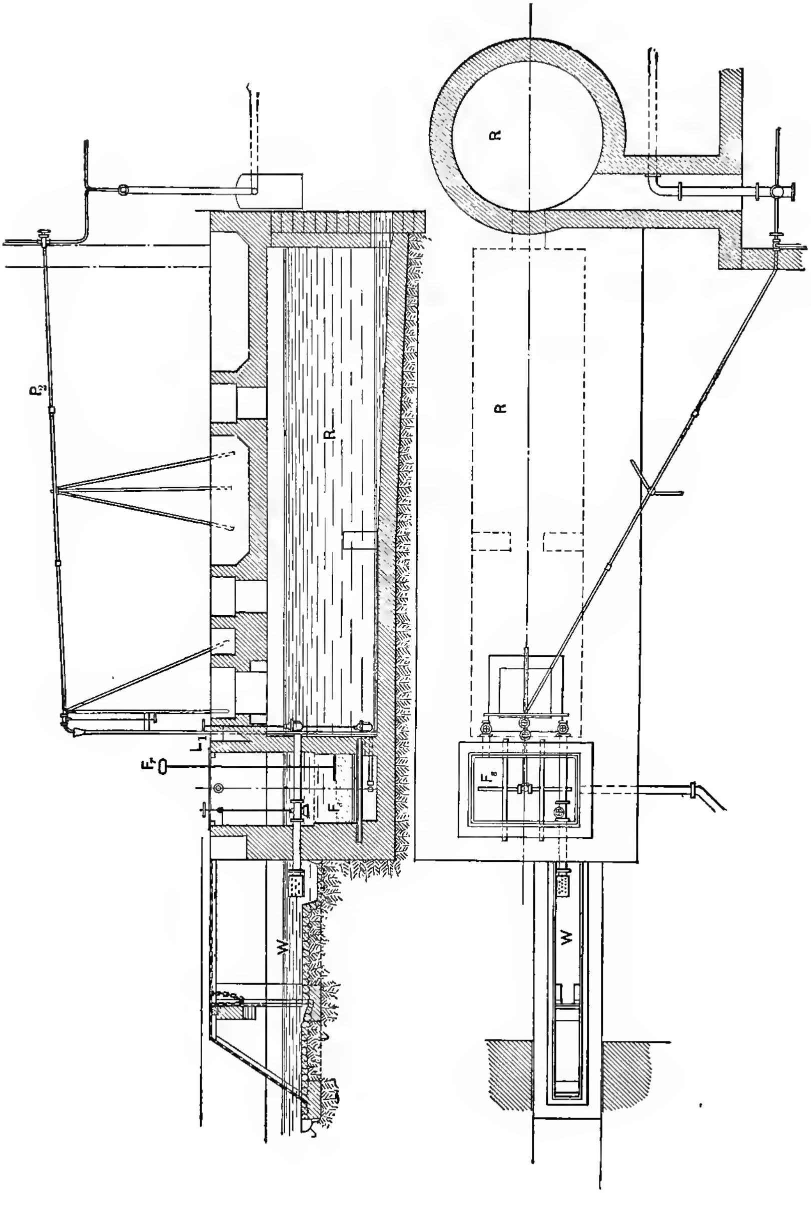

FIG. 168.

water and the washing out of the sand. The river-water, if it is pure, can enter directly behind the transverse wall into the cistern; but when it is polluted, it passes through the layers of sand from the top to the bottom and the necessary difference in pressure is produced by pumping from the cistern. For washing out the sand filters water will be brought from the pipe overhead, carried by wooden or iron supports so arranged that the vertical pipe placed with its mouth under the sand will carry along air, stir up the sand and wash it.

The stirring up of the entire surface of the sand will be aided by means of a stirring-screen operated by hand.

CHAPTER XII.

REPORT ON WATER SOFTENING BY THE SOCIETY OF GERMAN RAILWAY MANAGERS.

German Railway Managers' Report.

THE report of the technical committee of the Society of German Railway Managers on the question, Which method of purification of boiler feed-water has shown itself best by long use? is of special interest.

This report was rendered on the part of the Austrian Northwestern Railway, and is open for inspection in the 13th supplementary volume of the Organ für die Fortschritte des Eisenbahnwesens (Organ for the Advancement of Railway Affairs).

As it is of special value in connection with the criticism of water-purifying plants for railways, it is here given as follows:

REPORT ON THE ANSWER TO THE QUESTION, GROUP VII, NO. 5, FEED-WATER.

Which system of purifying boiler feed-waters has shown itself the best by long use?

Answer. The Austrian Northwestern Railway.

This question was answered more or less by twenty managers.

A. Of the twenty managers, in more than fifty cases, eighteen used the chemical system of water-purification based on Stingl's logical method of precipitating the calcium, magnesia, and iron out of the cold water, before entering the boilers, by means of special machines.

The managers' report is as follows:

1. Grand Duchy of Baden National Railway. It has had

in operation three large plants of the Reisert-Dervaux systems at

Lauda Station	20	cubic	meters	capacity	since 1893,
Heidelberg Station	60	"	"	"	" 1897,
Osterburken Station	20	"	"	"	" 1900,

as well as smaller plants of the same system in the electric plants of Mannheim, Brucshal, and Karlsruhe.

In the stations at Heidelberg and Osterburken the exhaust steam of the steam-pump is used for heating (insufficiently) the purified water.

The water-purification system is of great advantage, so long as, with the softening, the hardness does not go below 9° German.

2. Imperial Bavarian National Railway. It has large water-purifying plants, of the Reisert-Dervaux, Humboldt-Gaillet, and Desrumeaux systems, at the Augsburg, Ingolstadt, Landshut, Plattling bei Ulm, Würzburg stations, and several smaller plants in operation with success.

3. Lübeck-Büchener Railway Co. The boiler feed-water is submitted to a chemical purification according to the method of Dehne. It is not, however, satisfactory in practice. The very hard water is made suitable for use.

4. K. E. D. Berlin. It has used a plant on the Reisert-Dervaux system, for three years at the Stettin Railway Station in Berlin and for two years a plant of the Dehne system at the Potsdam Railway Station in Berlin. Both machines have proved themselves satisfactory on the whole; yet, until the present period of operation is closed, this cannot be known.

5. K. E. D. Breslau. They have had installed for a short time a small plant of an unnamed system. The peculiar conditions of its operation will not allow of a conclusion as to its general application.

6. K. E. D. Cologne. The patent water-purifiers of Reisert-Dervaux and Desrumeaux-Kyll have proved themselves satisfactory for a long period.

7. K. E. D. Erfurt. The boiler feed-water purifying plant on Dehne's system has proved itself satisfactory. Other devices are not in use to an extent worth speaking of.

8. K. E. D. Hanover. They have used the purifying system of Reisert-Dervaux, and in one plant the Dehne system, with good results. This management expressed no definite opinion on the Reichling system.

9. K. E. D. Madgeburg. Until now, they have only had several water-purifying plants of the Dehne system. They alluded to the manipulation of the filter-press requiring much time, to the inconvenient removal of the refuse, and to the rapid wearing out of the filter-clothes.

10. Imperial Saxon State Railway. They have in operation in all, at six different locomotive stations, water-purifying machines of the Berenger-Stingl system.

Three of these devices were out of service on account of obtaining a better water.

One machine was used for the clarification of the soft river-water before use.

One machine was used since 1884 to take out the iron from 750 to 800 c.m. of water daily.

One machine served for the chemical precipitation and removal of calcium salts.

Both machines used for the chemical purification have proved satisfactory.

11. Imperial Würtemberg State Railway. Has six purifying plants at present,—five Reisert-Dervaux and one unnamed system. The plants deliver from 15 c.m. to 500 cm. per day. They have been in operation since 1900 and 1897.

It is intended to steadily and consistently build water-purifying plants on the railway projected to Metz.

12. K. K. Emperor Ferdinand's Northern Railway. Since May, 1900, a plant of Wehrenfennig's system has been in operation, which up to the present has worked without stopping, and accomplished the improvement of the feed-water striven for with success.

13. K. K. Government Railway. The latter gives the preference—among the purifying plants investigated, which were the systems of Dervaux, Reisert-Dervaux, Dervaux-Wehrenfennig, and Desrumeaux—to that of Reisert-Dervaux.

14 and 15. K. K. Austrian Northwestern Railway and Southern-North German Junction Line. From 1870 to 1878 they had in operation two plants of the Berenger-Stingl system, one at Caslau of 9.5 c.m. capacity, and one at Vienna of 15 c.m. capacity, as well as two plants of Wehrenfennig's system, one at Zellerndorf of 18 c.m. capacity, and at Josefstadt of 10 c.m. capacity. These plants have proved themselves satisfactory.

16. Austrian-Hungarian National Railway Co. A large apparatus of the Berenger-Stingl system for purification of boiler feed-water has been in operation for many years at the Vienna Station, which has always proved satisfactory.

A smaller apparatus of the Dervaux system is in use at a larger boiler-plant, and also gives satisfactory results.

17. K. K. Southern Railway Co. Has one apparatus of the Berenger-Stingl system, but which has became insufficient on account of the increased demand for water; the reconstruction of this plant is under consideration. By means of a purifying plant of Wehrenfennig's system at a smaller station, the formation of scale is greatly diminished, and the destruction of the valves of the injectors has been prevented since the installation of this method of purification.

18. Imperial Hungarian National Railway. Water-purifying apparatus of the Berenger-Stingl system is used at the Uszög and Pécs stations. The water becomes entirely free of precipitate and is softened for use.

At the Cis-Czell station an apparatus of the Pollacsek system is placed which softens a water of 30° to 14.6° of hardness.

B. Plants in which soda-ash and caustic soda are added to the tanks of the water-stations.

1. The Imperial Hungarian National Railway mixes caustic soda in the raw water in the water-tanks of seven stations

where the water-consumption is small. The raw water stands 5 to 6 hours after being stirred up with the caustic soda, so that the precipitate can settle to the bottom.

The precipitate must be often removed, in order to prevent the stoppage of the outlet pipe.

2. The Holland Railway Co. The treatment has proved itself satisfactory.

3. The Company for the operation of the Netherland National Railway. Special devices are not used.

C. Additions of soda-ash as well as caustic soda are added to the water in the tenders with success, where the raw water is high in gypsum, by the National Railway of the Grand Duchy of Baden, as well as the Imperial Hungarian National Railway, which latter express themselves as perfectly satisfied, on the whole, with the results as well as the insignificant cost. The K. K. Austrian Northwestern Railway and Southern-North German Junction Line has used soda-ash and caustic soda treatment in the tender-water at several stations.

The Austrian-Hungarian National Railway Co. in general employ the addition of chemicals to the feed-water.

D. The Imperial Hungarian National Railway Co. introduces soda-ash, dissolved in warm water, into the inside of the boilers after the boilers are washed out, by which the old scale is dissolved, the formation of new scale is prevented, and the spongy, flaky precipitate formed is removed by means of the wash-water. The addition of mineral oil to the boiler-water is being investigated at several stations. No report of the result is to be obtained.

The Imperial Bavarian National Railway, and the Imperial Saxon National Railway, and the Austrian-Hungarian National Railway Co. strive to obtain soft feed-water by means of pumping surface-water.

The latter management also obtained soft water by deep wells, which, for example, has been done with success in Bavaria, at Münich, and Nürnberg.

F. The Imperial Saxon National Railway improve their turbid river-water at one station by mechanical clarification, and the Lübeck-Büchener Railway Co. use the same means at two stations.

G. The Imperial Saxon National Railway Co. sought to prevent the accumulation of scale by means of frequent blowing-out of the boiler-water (between the regular periods for cleaning).

Regulation of the Devices used for the Chemical Purification of Water.

On the regulation of the water-purification several managers give only general suggestions.

The Grand Duchy of Baden National Railway, for example, exhibit the open and closed regulation of the Dervaux machines on a water-purifying plant of 60 c.m. capacity, which consists of two separate machines, each of 30 c.m. capacity.

For the distribution of the reagents they use the closed lime-tank (placed on the ground level) at the stations at Lauda and Osterburken and open lye-reservoirs; at the Heidelberg station they use the open regulation, and introduce the lime into a mechanical stirring device. The requirements of the lime and soda-ash are met by a pump.

In stations at Heidelberg and Osterburken, gravel-filters are used, which are washed out by means of steam, air, and water.

The K. E. K. Berlin remarked that the purification of water by their Dervaux apparatus was completed in open reservoirs, and by their Dehne system in closed chambers, by filter-presses.

The K. K. Austrian Northwestern and Southern German Junction Railway presented sketches of the regulation of their water-purifying devices, and gave a description on the length of time required by the water (which has so much influence on the results of purification) to pass through the clearing-tank; on the velocity of the rising current of water in the latter; on the manner of preparation and the measuring of the reagents; the clearing height; the employment and manipulation of the wood-fiber filter; and whether the manipulation is from above the reservoirs or on the ground level; and whether the water-purifying device required buildings or not.

The Imperial Würtemberg National Railway uses sand and wood-fiber filters with their Dervaux apparatus.

The Imperial Hungarian National Railway report that in the Pollacsek system the purification-tanks are built in the inside of the water-reservoirs.

Removal of the Precipitated Material from Purifying Devices.

Grand Duchy of Baden National Railway. The precipitate produced in the water-purifying plant is collected in a drain, in the waste-channel, or in the lower part of the reservoir, to which it settles. The water standing above flows constantly to the purifier.

K. E. D. Magdeburg. The removal of the refuse (Dehne system) is inconvenient.

Imperial Würtemberg National Railway. With their water-purifying plants, in which caustic soda only is used, only a small amount of refuse is created, about .3 liters per c.m., while in water-purification with lime and soda-ash a considerable quantity (1.5 liters per c.m.) of precipitates was thrown down.

The precipitate discharged from the plant is scooped out regularly every six to eight weeks and carried away.

The removal of the precipitate usually occasions the greatest difficulty. In one plant a slime-pump, operated by three men, is in use. Later, a device for raising the slime was gotten up.

Imperial Hungarian National Railway. The removal of the precipitate from the water-station reservoirs, where the water is treated with caustic soda, must be made frequently, in order to prevent stoppage of the discharge-pipe.

Results of the Chemical Purification of Water in the Preceding Stationary Plants.

Only a few companies made more or less complete reports on the character of the raw water, the amount of additions, the degree of softening, and the alkalinity of the pure water, as may be seen in table (pages 264 and 265).

The Grand Duchy of Baden National Railway set the limit of softening at 9° German, because a greater softening causes foaming; the trifling heating, which is imparted at Heidelberg and Osterburken by means of the exhaust steam from the steam-pump, is not sufficient to effect any considerable precipitation of lime.

The K. E. D. Hanover keeps the soda-ash addition 25% below the permissible amount, in order to prevent foaming, but adds so much saturated lime-water that the lime-salts are removed as completely as possible.

Imperial Saxon National Railway. A test of the water is made periodically, as follows:

1. By the addition of a small amount of oxalate of ammonia, in order to see to what extent the purified water is free of calcium.

2. By the addition of several drops of phenolphthalein, in order to determine that the purifying chemicals have not been used in excess.

The K. K. Austrian Northwestern and Southern North German Junction Line report that the degree of softening depends on the strength of the raw water in magnesia, and that the accuracy with which the reagents were measured, the size of the settling-chambers of the clearing-tank, the time required for passage of the water through the former, and the rate of velocity of the rising current of water in the former, as well as the filtration, all were of influence on the resultant purification.

They also made full reports on the characteristics of the raw water which are necessary for the calculation of the reagents (see *Organ*, 1893), and to thereby diagnose the characteristics of the pure water, and, in addition, the amount of the total hardness, as well as that of the alkalinity thus produced (measured by the titration of 56 c.c. of water with 2/10 normal HCl with phenolphthalein used as an indicator).

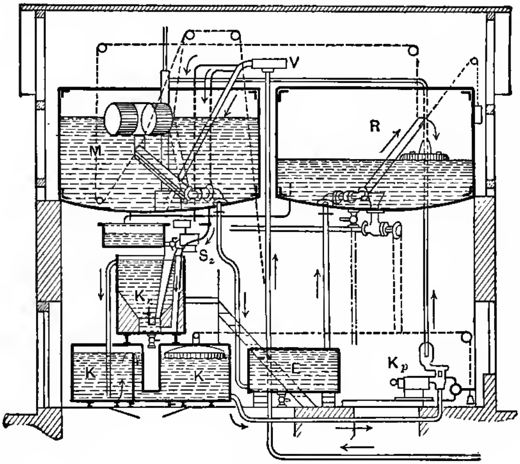

FIG. 169.

Explanation of Letters in Figs. 169–171.

R, Tank for pure water;
Mk, " " clarification;
Mm, " " mixing;
F, Filter;
Vw, Distributor for raw water;
Vm, " " prepared water;
K, Chamber for preparation of lime-water;
KS, Reagent water-chamber;
Sl, Chamber for preparation of soda-ash;
Sz, Soda-ash distributing-chamber;
Dk, Pressure-regulator for lime-water;
Dks, " " caustic soda;
Kp, Pump for reagent water;
A, Removal of precipitate.

N.B.—Reservoirs *R*, *Mk*, *M* were already on hand for carrying on the water-purification.

These tests of the purified water were then completed by the addition of oxalate of ammonia to determine if the purified water was free from lime, and by the addition of lime-water, in order to see if no excess of lime-water or soda-ash is present (see *Organ*, 1893).

First Cost of Purifying Plants.

Imperial Saxon National Railway. A not inconsiderable cost is connected with water-purifying plants.

Imperial Hungarian National Railway. The cost of water-purifying plants of the Berenger-Stingl system is high.

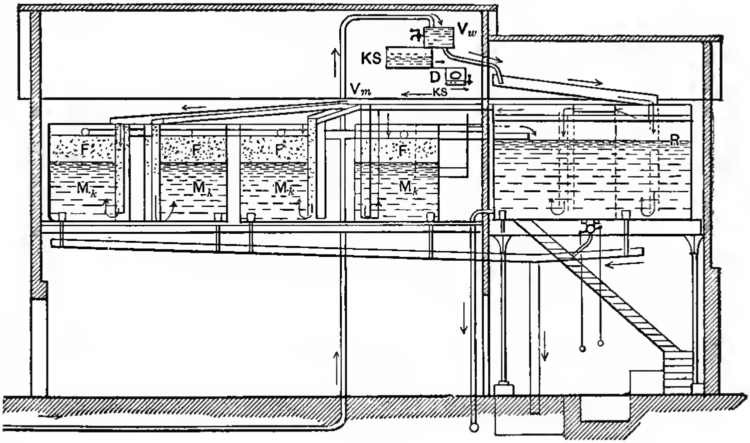

Fig. 170.

K. K. Austrian Northwestern Railway and Southern North German Junction Line. As a result of the design of the plant at Zellerndorf* (Fig. 169) and at Josefstadt (Figs. 170 and 171), both after the Wehrenfennig system, they were both built in the existing water-station buildings and tanks, and therefore no expenditures were required for buildings or clearing-reservoirs, by which a considerable cheapening of the plants was made possible.

---

* See, also, *Organ*, 1899, Vols. X and XI.

Cost of Operation and Attendance of Water-purifying Plants.

Grand Duchy of Baden National Railway. It consists chiefly of the cost of the materials, lime and soda-ash, which amount to 2.5 pfennigs per cubic meter. ($.006 for 262. gals.)

At three stations equipped with water-purifying plants the pump-runner takes care of the work of adding the lime and soda-ash, so that no further increase of daily operating expense is caused.

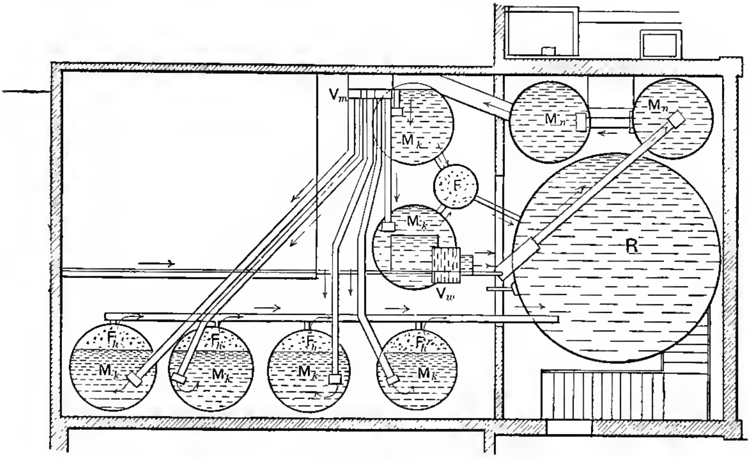

Fig. 171.

The charging at Heidelberg and Lauda takes place three times a day. Additional help is only required twice a year for cleansing the lime-saturator and apparatus. At the Heidelberg and Osterburken stations, gravel-filters are in use, which consume steam and water for washing out.

K. E. D. Magdeburg. The filter clothes used for water-purification in the Dehne system are quickly worn out. The manipulation of the filter-press is very tedious. The removal of the refuse is inconvenient.

Imperial Saxon National Railway. A considerable cost is connected with the plants.

Imperial Würtemberg National Railway. The removal of the precipitates is connected sometimes with a considerable cost.

Each cubic meter of purified water costs 2 to 2.5 pfennigs, according to the hardness of the water. (2 to 2½ cents per 1000 gals.)

With water purified with caustic soda alone, the cost per cubic meter is about 1.2 pfennigs. ($.012 per 1000 gals.)

The personnel is of little consequence, so long as the additions are looked after by the operator of the pumping- or fire-room.

K. K. Government Railway. The cost of purification on the average is two farthings (heller) per cubic meter. (2 cents per 1000 gals.)

K. K. Austrian Northwestern and Southern North German Junction Railway. The cost of purification, without the attendance, actually amounts to,—

in Vienna......	5.5	cents	per	1000	gals.
" Caslau..... .	7.3	"	"	"	"
" Zellerndorf. . .	3.9	"	"	"	"
" Josefstadt. . . .	5.6	"	"	"	"

The changing of the wood-fiber takes place every three to six weeks, and increases the cost of each cubic meter about .3 farthings (heller). ($.003 per 1000 gals.)

The Austrian-Hungarian National Railway Co. The operation of the purifying plants is always accompanied with a considerable cost.

Imperial Hungarian National Railway. A special staff of attendants is necessary for the water-purifying plants of the Berenger-Stingl system.

Beneficial Influence of the Pure Water on the Operation of Boilers.

Grand Duchy of Baden National Railway. The leaky tubes and stay-bolts have been greatly lessened.

The fire-tubes are entirely empty, and only a flour-like lime-powder, easily washed off, lies on the fire-box.

By its use a better conduction of heat and a larger life of the heating surfaces is obtained.

Company.	Station.	Characteristics of the Raw Water.					Addition per One Cubic Meter in Kilograms.			Characteristics of the Purified Water.		System.
		German Degrees of Hardness.										
		Total.	Temporary.	Permanent.	$CaH_2(CO_3)_2$.	$CaSO_4$.	Lime, 90%.	Soda Ash, 98%.	Soda Caustic.	Total. Hardness.	Alkalinity.	
Grand Duchy of Baden National Railway......	Lauda	18.5°	......	......	......	......	.25	.05	......	9°	......	Reisert-Dervaux
	Heidelberg	14.6°	7.4°	7.2°	132 grs.	175 grs. per liter	.13	.02	......	8°–9°	......	" "
	Osterburken	20.2°	13.6°	6.6°	243 grs.	100 grs. per liter	.36	.06	......	8°–9°	......	" "
K. E. D. Hanover	....	......	......	......	......	......	Enough CaO so that the CaCO is completely precipitated. The addition of soda-ash is 25% below the permissible amount.		......	......	......	Reisert-Dervaux and Dehne
Emperor Ferdinand Northern Railway......	....	39°–45°	......	......	......	......	......	......	......	8°–14°	......	Wehrenfennig

Company.	Station.	Characteristics of the Raw Water.						Addition per One Cubic Meter in Kilograms.			Characteristics of the Purified Water.		System.
		German Degrees of Hardness.											
		Total.	Temporary.	Permanent.	CO_2.	CaO.	MgO.	Lime 90%	Soda Ash, 98%.	Caustic Soda.	Total Hardness.	Alkalinity.	
Austrian North-Western and Southern North German Junction Line......	Vienna	39°	......	......	19.7°	25.0°	14.0°	.16	.38	.....	11°–125°	2°–4°	Berenger-Stingl
	Caslau	39.4°	......	......	25.5°	29.6°	9.8°	.24	.27	.....	12°	3°	"
	Zellerndorf	24°	......	......	19.6°	16°	8.0°	.26	.087	.....	5°–8°	2°–3°	Wehrenfennig
	Josefstädt	29.7°	......	......	12.88°	25.7°	4.0°	.17	.33	.....	4°–5°	0°–1°	"
Imperial Saxon National Railway..........	....	14.0°	3°	11°	......	......	......	.04 .02	....	80% .035 80% .160	4°–9°	......	Berenger-Stingl
Imperial Hungarian National Railway.......	Uszög Pécs	21°	......	......	......	......	......	....	....	.....	5°–6°	......	"
	Kis-Czell	30°	......	......	......	......	......	....	....	.....	14.6°	......	Pollacsek
K. K. Southern Railway..	....	29°	......	......	......	......	......	....	....	.....	8.9°	......	Wehrenfennig
Imperial Würtemberg National Railway......	....	14.3°	......	......	......	......	......	.23 to .32	.15 to .18	96% .07 to .08	....	......	Delvaux-Reisert
											5°–6°	......	Unnamed

All results are given in German degrees of hardness. The quantities of CO_2 and MgO, as well as the degree of alkalinity used are calculated to calcium (CaO) by HCl. (See *Organ*, 1893.)

Interruption of the operation on account of leaking tubes is largely done away with.

On economy of fuel no data can be given.

K. E. D. Breslau. The expenditure for the repairs to boilers is lessened by water purification.

The necessary outlay on account of the purification will be more than counterbalanced by better utilization of the fuel and by higher yearly efficiency of the locomotive.

Imperial Würtemberg National Railway. With switching-engines which are only filled with purified water, general repairs are seldom needed, and only in the rarest cases are the tubes taken out. The stay-bolts are full size. The daily leaking of tubes and thinning (corrosion) of the fire-box is done away with.

In locomotives, which are filled with both purified and unpurified water, scale-formation has been hindered and only slime forms, which may be removed by washing out every eight to twelve days.

The labor on the fire-box is lessened. Economy of fuel is effected.

K. K. Southern Railway. Since the introduction of water-purification, the destruction of the valve-cases of the injectors, which formerly took place after a brief period, has been done away with.

Disadvantageous Influences of the Pure Water on the Operation of Boilers.

Grand Duchy of Baden National Railway. Large additions, especially of soda-ash, with the heating in the locomotive boiler cause a violent foaming, which, with the splashing and spitting of the locomotive, cause a strong priming of water into the steam-chest and cylinders, as well as a deposit of lime on the slide-valve and surface of the cylinders, which again causes greater friction and scoring.

It was originally caused on account of the claim of the

Reisert Company that the hardness of the water would be reduced to 4°. As a result of the large soda-ash additions, and on account of the great delays and interruptions to the operation caused by the disturbance of the water, it was made necessary to keep the blow-off valve open for a long period.

For the last three years, such disturbances have not taken place, but the hardness is not brought down below 9°.

For this reason the water in the boiler is not made too strongly alkaline, but it must be let out at least every eight days.

As the freight trains are suspended on Sunday, the addition of lime and soda-ash is omitted from early Sunday evening until Monday noon, because it has been proved that, in the water resting over Sunday, the most strongly alkaline part of the former settles to the lower part of the reservoir, so that the locomotive, which first takes water on Monday, obtains the most strongly alkaline water and foams.

K. E. D. Hanover. As drinking-water, and as water for animals, the water purified with chemicals is not free from objections.

Conclusions.

All systems for making scale-forming feed-water more suitable for use by treatment with lime, soda-ash, or caustic soda (in suitable mixing and clearing devices), or with soda-ash as well as caustic soda in the water-station tanks, the tender-tanks, or in the boiler itself (without special devices), have effected a substantial softening of the water, and a satisfactory improvement of the operating conditions and on the maintenance of the boilers.

(On the results of the use of mineral-oil additions to the boiler-water, reports are lacking.)

The degree of the improvement described above is dependent on,—

(*a*) The characteristics of the raw water (its changeableness, its strength in magnesia, its temperature).

(*b*) The period of time during which the chemicals are stirred with the water to be purified.
(*c*) The pressure under which this occurs.
(*d*) The uniformity of the strength of the reagent liquids.
(*e*) The proper measurement of the reagents, and
(*f*) The reliability of the attendant.

With a continuously similar character of raw water, with an always uniform strength of the reagents in effective material, with a long period of continuous, uninterrupted operation of the water-purifying plant, and with the use of properly proportioned additions for the given case, the best results of the cold purifying process may be expected.

This is particularly true if the purifying process is aided by a sufficient heating of the raw water, but this cannot, for example, be accomplished by exhaust steam.

It appears, in addition to the above, that, where the character of the raw water requires the purification with caustic soda only, an especially satisfactory result is obtained; while raw water with a high content of magnesia permits of no very complete softening, as in this case the pure water causes foaming in the locomotive.

The volume of the purifying apparatus is essential to the result, as this determines the relation between the quantity of water entering each second or each day, to be purified, and the thickness of precipitate thrown down.

A comparison of the worth of the various purifying devices to each other, based on this report, is not possible, because most of the companies have not made any statement on the character of the raw water, the volume of the machines, the duration of the uninterrupted daily operation, and because a statement was only received from one company on the strength of alkali remaining in the pure water.

Further, only a few replies were made on the regulation, the removal of the precipitate, the result of purification, the testing of the pure water, the cost of the plant and cost of operating, as well as the attendance; but, from the statements made, so much may be stated, that in recent times the value of a purifying plant will depend,—

1. On the relative cost of a soft natural water, if this is only obtainable at high cost, either from surface sources or deep wells, whether the installation of water-purifying plants is desirable or not;
2. On a good previous clarification for increasing the period of operation of the filter, and to obtain a good filtration. A good clarification is also necessary in order to keep the delivery-pipes clean;
3. On correctly made tests on the alkalinity of the pure water;
4. On frequent changes of the water in the boiler;
5. On cheap first cost of the apparatus, now generally quite expensive, by building it in the water-tanks;
6. On cheap and easy manipulation by the preparation of the chemicals on the ground level;
7. On a simple definite distribution through the employment of a weir properly divided;
8. On simple means of removing the precipitate.

Under all circumstances a beneficial influence of water-purifying plants will be noticed on the maintenance of the fire-box, tubes, and injectors, on the economy in consumption of fuel, and on the yearly service of the locomotives.

In conclusion it must be noted that the purified water is not free from objections as a drinking-water and water for animals.

In most cases of mechanical pollution of water, filter-plants suffice.

CHAPTER XIII.

METHOD OF TABULATING DATA.

It is recommended to always tabulate a detailed account of the origin of the water under consideration, its physical and chemical characteristics, its action on the boiler, its method of acting, and its chief use, etc., in the following manner.

Data Regarding Sampling of Water.

No. ——.

I. HISTORY OF THE SAMPLE.

Progressive number of water sample:		
Data regarding the taking of the sample:		
Designation of the water:	If flowing (spring-, brook-, river-, pond-, or well-water):	
	From what place it was taken, if several samples are obtained:	
Surroundings of the spring:		
Manner of conveyance:	If in wooden or iron pipes, in open channels, or in any other manner:	
State of the weather	at the time of taking sample:	
Temperature of the water		
Condition of the water (high, medium, or low water)		

Any harmful additions in the immediate neighborhood. Origin of the above practice. Kind of these pollutions and factories causing same.

....

....

....

....

....

Taste	of the water:	
Smell		
Color		

Special remarks with reviews on the use as feed-water:

....

....

....

....

If, and in what way, and to what extent, the iron parts of the pump or the water-reservoirs or the plates of the tenders are attacked by the water:

....

....

....

If the water conduit-pipes are stopped by hard incrustation, by algæ, or by easily moved slime, in what manner and to what degree:

....

....

....

If the water is already clarified, purified, or filtered in any way:

....

....

....

If the water-station boiler or the other boilers fed with this water are corroded, in what way, in what places, and to what extent :

....

....

Special notes in regard to the behavior of the water:

....

....

If a boiler feed-water preheater is present for the water-station boiler:

....

....

Daily number of hours of operation of the water-station boiler:	
Yearly hours of operation of other boilers fed with this water:	

Characteristics of the boiler-scale or boiler-slime:	Color:.................................... Quantity:.................................. Consistency:...............................

Total water	Inlet	per 24 hours:	
	Demand		

Demand for water in 24 hours:	(*a*) for feeding boilers:.............................. (*b*) for washing out boilers:.......................... (*c*) for miscellaneous uses:........................... (*d*) for drinking-water:...............................

II. CHEMICAL CHARACTERISTICS OF THE WATER.

Reaction of the raw water:	
Reaction of the heated water:	

In 100 Liters = 100,000 Grams of the Raw Water there is contained:

	Grams.			Grams.	
	Actual.	Calculated as CaO.		Actual.	Calculated as CaO.
Bound carbonic acid, titration with $^2/_{10}$ normal HCl.......	......		Calcium.............	......	......
Sulphuric acid.......	......		Magnesia Iron oxide Alum. oxide determined together	....	....
Chlorine...........	......	......	Ammonia.............	......	......
Nitric acid..........	......	......			
Nitrous acid........	......	......			
Hydrogen sulphide...	......	......			

Acids calculated as calcium (CaO): .... Bases: ....

Organic substances, and organic substances requiring oxygen contained in 100,000 grams of water in permanganate of potash, in grams. Residue by evaporation (obtained by evaporation of 2 liters of water) per 100 liters:. . . . .

Color and character of same:. . . . .

. . . .

. . . .

Amount of iron in hot water:. . . . .

. . . .

Amount of iron in the boiler-scale or precipitate (in water-station boilers):

. . . .

Appearance of the water on boiling:	Coloration: . . . .
	Precipitation: . . . .
	Coating of the heating-flask: . . . .

Alkalinity (titration of 100 cu.m. of water with $^1/_{10}$ normal HCl. Amount of cubic centimeters of latter used):. . . . .

Total hardness in German degrees (1 German degree corresponds to 1 part CaO in 100,000 parts of water *) calculated from the sum of the CaO and the magnesia, oxides of iron, and alumina calculated to CaO:. . . . .

. . . .

Total hardness determined directly in German degrees of hardness with soap solution according to Clark's method:. . . . .

. . . .

Permanent hardness (according to the old method) in German degrees of hardness with soap solution according to Clark, found by the heating of raw water and filtering (diluted with distilled water and evaporated to the original volume):. . . . .

. . . .

Permanent hardness (according to the new method): difference between total hardness and alkalinity × 2.8: . . . .

Temporary hardness, difference between total and permanent hardness (according to old method): . . . .

Temporary hardness: Alkalinity × 2.8 (according to new method): . . . .

. . . .

Bound carbonic acid in the boiled and filtered water as in the determination of the permanent hardness, found by titrating with $^2/_{10}$ normal HCl:

. . . .

---

* 1 German degree of hardness = 1.25 English = 1.79 French degrees of hardness

The Permissible Limits for Drinking-water are (Grams in 100 Liters =100,000 Grams):

	According to		According to		According to	
For Organic substances.	Reichardt	.4	Kubel	.8	Pettenkofer	1.0
" Ammonia.	"	.0				
" Nitrous acid. .	"	.0				
" Nitric acid. . . .	"	.4	Dr. Fischer	2.70	Dr. Medicus	.5–1.5
" Chlorine.	"	.2–.8	" "	3.55	" "	2–3
" Sulphuric acid	"	.2–6.3	" "	8.00	" "	8–10
" Hydrogen sulphide.	"	.0				
" Magnesia.	Schulze	10.	" "	4.–5		
" Calcium.	Dr. Fischer	18.–20–25	(The larger amounts are obtained by weighing the contents in bicarbonate of calcium.)			
" Residue on evaporation	" "	10.–50				

The water must further be clear, colorless, and odorless; the temperature may only vary a few degrees in different seasons of the year, and it may only contain a small amount of organic material and no organisms of putrefaction. Microscopic examination is necessary.

III. RESULTS OF THE COLLECTION.

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

IV. INDEX

of the Disposal of the Water from. . . . .

Date.	Year.	Record Number.	Subject.
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .
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